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LOW TEMPERATURES AS A LIMITING FACTOR IN WESTERN PINE BEETLE EPIDEMICS

Progress Report No. 1

by

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Portland, Oregon
April 20, 1933

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Introduction

Only a few years of observation of the behavior of native barkbeetle outbreaks is sufficient to convince one that epidemics of these insects rise and fall through the operation of natural control factors. Insect parasites and predators, birds, temperature and moisture are a few of the natural factors which have been considered as playing an important part in determining epidemic trends.

That cold weather is a limiting factor of major importance has been recognized for many years in connection with outbreaks of the southern pine beetle. Since 1924 it has been known as also playing an important part in halting outbreaks of the western pine beetle. But not until the widespread destruction of beetle broods during the past winter did we realize how truly important this factor might be. Over a large part of the ponderosa pine belt in Oregon and California from 30 to 85 percent of the western pine beetle broods have been killed, in many cases a higher percentage than is usually secured from control operations. As a consequence, control work, under way was halted and a detailed study of the results of the cold spell started.

On December 8th to 15th, when the cold wave spread over the Northwest, two control projects were in operation, one in California on the Modoc National Forest, and the other on the Ochoco National Forest in Oregon. When temperatures dropped to 19 degrees below, injury to the broods was simultaneously recognized as possibilities on both areas and bark was collected and sent in to the laboratories at Berkeley and Portland for examination. Mortality was found to have occurred on both areas. The Modoc samples showed a mortality of 65 percent and this project was promptly closed. On the Ochoco the samples showed a 50 percent mortality and work was modified to the extent of treating only the thicker bark trees, until a more detailed analysis of samples could be made. At the end of January this project was also closed down and additional mortality from a freeze in February settled the advisability of its continuance.

Through arrangements with Mr. Miller a cooperative study was started to determine the general effect of the cold spell throughout Oregon and Washington. This was to be done by

(1) Brood analysis of bark samples sent to the laboratory by forest officers from various parts of the region;

(2) Bark counts from these same areas following emergence of the beetles, to determine ultimate effect upon beetlepopulations;

(3) Surveys of forest areas following attacks to determine final effect upon epidemic trends

In addition, it was planned to determine the relationship of air to bark temperatures if a favorable opportunity presented itself. Through a fortunate set of circumstances this was made possible in early February at a time when a new low record was established for the state of Oregon.

Methods

Bark from infested ponderosa pines was collected in the field by members of the station and by Forest officers and brought or sent in to the laboratory at Portland for examination.

In the laboratory the bark was carefully shaved up, and the dead and living larvae counted. In the early stages larvae killed by freezing are easily recognized, having a characteristic distended appearance and gradually turning yellowish brown to black. After a month or more the dead larvae shriveled to mere black specks and it became much more difficult to recognize them.

Basis

The data summarized in the following report is based upon the examination of 1200 bark samples collected from 28 different areas distributed throughout the ponderosa pine region of eastern Oregon and Washington. These samples represented a total of 782 square feet of infested bark containing 147,619 living or dead larvae per square foot. This large series of examinations gives a good basis for the conclusions which are presented in the following report, especially as to the immediate effect of low winter temperatures in destorying bark beetle broods: The subsequent effects will be presented as the study progresses.

History

The first case where low winter temperatures were believed to be responsible for the death of hibernating broods of the western pine beetle (Dendroctonus brevicomis Lec) was reported in 1924 by A. J. Jaenicke of the Forest Service. He found that a high percentage of the overwintering larvae were dead following low temperatures of from -20°F. to -25°F. near Bend, Oregon. This mortality of approximately 82 percent could be accounted for only as a result of freezing of the larvae in the outer bark.

Immediately following the winter-kill of broods of the western pine beetle in the field Miller (7) began a series of laboratory experiments to determine the low temperatures which result in the death of the overwintering brood stages. He determined low lethal temperatures for the various brood stages of this insect from the Sierra Nevada region, and for a limited number of insects from the Coeur d'Alene region. He found that partial mortality occurs at zero, Fahrenheit, and practically no larvae survive -10°; and that larvae which had passed through the overwintering condition at Coeud d'Alene, Idaho, developed high mortality when air temperatures were reduced through the range from 0 to -10°. About 25 percent survived a temperature of -10°, but mortality was practically complete at -18°.

Miller (7) also reported the results by Evenden and Rust to determine the difference between air and bark temperatures in the field during cold weather. During two cold periods in 1927 and 1928 thermometers were placed beneath the bark of a standing infested tree. Others were suspended in the air and hourly readings taken for 28 hours. They found that at an air temperature of -6°F. corresponding bark temperatures were 4° and 6°. This showed a difference of 10° and 12° between the air and bark temperatures.

The first results of the recent freeze on the Modoc National Forest were covered by Miller in an article published in the Journal of Forestry, April 1933. (8) In this paper he reports a 65 percent reduction in the total beetle population within the control area and the consequent closing down of the control project. The bark examinations, upon which his conclusions were based showed a very considerable variation in mortality but a "fairly consistent correlation between mortality and bark thickness; i.e., the thinner the bark the higher the mortality." Also "a higher brood mortality was found in the full grown larval stage than the parent adult, egg or immature larval stage: "Field observations indicated that mortality was higher

in trees with loose bark than in those with tight bark;" that "mortality was higher towards the upper part of the trunk; and that "very little variation was found that could be attributed to site slope or difference in elevation." Most of these observations have been further substantiated by the findings covered in this report but contrary conclusions were reached as to the mortality in the immature larval stage, and the influence of loose or tight bark.

The Data

The information which so far has been secured by the workers at the Portland Station on the subject of western pine beetle mortality due to low winter temperatures, consists of three parts: (1) pertinent facts compiled from existing records in this office and that of the Forest Experiment Station; (2) intensive studies in the laboratory and field on the temperature-mortality relationships; and (3) extensive examinations of western pine beetle broods from areas scattered throughout the ponderosa pine belt of eastern Oregon and Washington.

Normal Mortality

For any insect species there is a more or less fixed loss or death rate which occurs from the time the eggs are laid throughout the immature stages and transformations until the adults emerge. This may be termed the normal mortality, and must be determined before abnormal or unusual mortality can be recognized as such.

Earlier studies (3) and (6) of the western pine beetle, particularly brood counts and bark examinations made in southern Oregon, have shown that living ponderosa pines are rather consistently attacked at the rate of 12 attacks or entrance holes per square foot, and for each attack 36 eggs are laid or a total of 432 eggs per square foot.

Limited count by Keen (5) showed that slightly over 20 percent of the eggs fail to hatch, which would reduce the number of young larvae to about 346 per square foot. The large number of bark examinations recently completed indicate that through January, February and March, the average number of full grown larvae is approximately 200 per square foot or a reduction of 54 percent since the egg stage. Referring again to the large number of bark counts which have been made in the past, the number of beetles which finally emerge per square foot averages about 63. Thus the normal hazards of life of western pine beetle broods from the egg to the adult stage disposes of about 85 percent of the progeny.

There is not a great deal of information as to the distribution of this mortality during the different stages and transformations of this insect. Beal's laboratory experiments on brood development of mature larvae of the western pine beetle (2) showed that very little mortality occurred during a stage but that a high mortality occurred during periods of transformation, from larvae to pupae or pupae to adults. These delicate changes are generally recognized to be critical points in the life of all insects. During Miller's freezing tests he found only a mortality of from 1 to 3 percent among full grown larvae of the western pine beetle due to other causes than from freezing.

Since the bulk of western pine beetle broods overwinter in the larval stage and during a period of at least three months no transformations take place, mortality from other causes during such a period is certainly very low. Moreover, periods of cold weather scarcely ever last for more than ten days or two weeks so that the mortality from other causes which might occur during such a short period of time is a very insignificant percentage; certainly not over 5 percent of the total. When we find then a sudden killing of from 65 percent to 85 percent of the brood within a period of a few days of excessive cold, the evidence is almost conclusive that this is the result of the cold and has little to do with normal mortality. On the other hand, a certain amount of winter mortality due to freezing may be the usual rather than the abnormal thing.

During brood examinations following within a few days of cold periods, it is easy to differentiate between larvae which have died as a result of the freeze and those which have previously died from other causes. In all of these examinations, a few dead larvae are found which apparently died from causes other than the freeze.

It is reasonable to assume that the death rate from other causes will continue among the surviving broods. Predators will take a toll, birds will continue to feed on the larvae in the bark, and the periods of transformation will exact a toll as they always have. In fact, some of these factors may be intensified as in the case where birds are obliged to concentrate their feeding on a small number of surviving insects. The net result, therefore, should be a further depletion of the broods escaping the freeze and a very low final emergence.

The Effect of Bark Temperature on Beetle Mortality

The western pine beetle like most insects is best adapted to carry on its activities within a limited range of optimum temperature conditions. As temperatures go below this optimum range, normal activity decreases until a point is reached where the insects become dormant. They may be still further undercooled to lethal temperatures or the death point beyond which recovery is impossible. Miller (7). It is this lethal cold temperature with which we are most concerned during cold winter weather. Although cold hardiness implies ability to resist not only intensity but duration of cold.

Miller (7), working on low temperatures lethal to the western pine beetle, found that under laboratory conditions mortality of the larvae followed freezing when bark temperatures were lowered below 0°F. He found that "partial mortality occurred at zero in broods which overwinter in the ponderosa pine belt of the Sierra Nevada region; that mortality at -5° exceeded 60 per cent; and that practically no larvae survived at -10°F."

Analysis of a limited number of bark samples which reached known temperatures under field conditions on the Ochoco National Forest, Oregon, shows a higher percent of survival at low temperatures (Table 1) and graph (1) than Miller obtained in his freezing tests. In field tests a survival of 27.6 percent was found at -17°F. This is probably due to one or a combination of many factors: first, the difference may be due to variation between field and laboratory tests; second, temperatures in the field reached their low point for only a very brief period, while in the laboratory they remained near the low point for three or four hours and in some cases, much longer; third, it may be due to the fact that a previous freeze had already killed about 50 percent of the broods and the remaining larvae may have been principally the hardier individuals; fourth, broods from eastern Oregon are probably more cold resistant than those from North Fork, California.

Table No. 1

Mortality of Western Pine Beetle Larvae Subjected to 26 Degrees F. Below Under Field Conditions

Bark Thickness	Bark Temperature	Larvae		Per Cent Mortality
		Living	Dead	
1/2 inch	-17	26	69	72.4
3/4 "	-14	40	72	64.0
3/4 "	-11	24	30	55.5
1-1/8 "	-5	71	68	48.9
1-3/4 "	0	170	86	33.5

Undoubtedly there is a difference in mortality which may be found under laboratory conditions and in the field. Since the insects are not under natural conditions in the laboratory it is not surprising that there is a greater survival in the field under similar temperature conditions.

In addition to intensity of cold we must take into consideration its duration, for it seems obvious that long periods of low temperatures should have a greater effect in destroying broods than a short period. The ability of an insect to withstand cold depends upon the quantity of heat or number of calories which are extracted from it and the longer the insect is exposed the greater the loss until the loss of heat reaches the fatal point. Payne (9), in working with oak borers, found that "insects which would survive a short exposure to temperatures slightly below zero were killed by long exposure at zero and at temperatures above zero".

In this connection a revies of Miller's laboratory experiments shows that after an exposure of an hour or two there was no additional mortality due to prolongation of the exposure. The same thing is reflected in the Ochoco experiments, so that we feel safe in concluding that any variationin mortality due to length of exposure is important only in cases where the exposure is for periods of less than two hours. This is another point upon which additional work in the laboratory is needed, but for practical purposes it is not of any great significance. Duration of air temperatures and its effect in bringing bark temperatures down to fatal levels is, on the other hand, of greatest importance.

The influence of moisture on brood mortality during cold periods has previously been demonstrated by Miller (7), working on the western pine beetle and by Beal (3) working on the southern pine beetle. They both found higher mortality among larvae in moist bark than among those in dry bark subjected to the same cold temperatures. The importance of moisture as affecting brood mortality was again revealed in the field examinations in eastern Oregon where mortality in winter infested (wet) trees

was compared with mortality in summer infested (dry) trees. Practically 100 per cent mortality was found in the green trees where most of the broods were still in the moist cambium, as against about 50 percent mortality in the summer trees where the broods were in the dry outer bark. This point was further emphasized by the analysis of a limited number of samples of moist bark containing small larvae. These results are presented in Table (2).

An examination of Table (2) shows that the mortality among small larvae occupying the cambium or moist inner bark is more than twice as high as for all ages of larvae occupying both the inner and outer bark. Since in nearly every case the mortality of the small larvae was 100 percent as compared with a mortality of from 16 to 74 percent of all larvae in the bark, this increase in mortality can most logically be attributed to the greater moisture content of the surrounding bark and its influence in connection with fatal low temperatures.

There is some evidence that a series of freezes have the effect of weeding out the less hardy individuals and allowing the survival of the more resistant strains. There is also the effect of repeated freezes tending to prepare insects for more rigorous conditions.

In Payne's (9) work with oak borers she found that during light freezes they became adjusted or hardened to cold and were thereafter better able to withstand lower temperatures during subsequent freezes. However, Miller found no such tendency on the part of the western pine beetle to become cold resistant through progressive shocking to permit of preparation for cold weather.

In the field living larvae were often found occupying the same bark layers as the dead larvae and so close to them that it would appear unreasonable that they were subjected to varying temperatures. That certain individuals were more resistant, either by nature, by preparation, or bodily condition, seems to be the only explanation.

Miller's (7) tests indicated that broods of western pine beetle which overwinter in regions where minimum winter temperatures are normally below zero apparently develop resistant strains which are better adapted to withstand cold than beetles from regions with milder winter climates. The Ochuco region is one in which subzero weather is not infrequent and it may be that the broods from this region are more cold resistant than those from California. Further laboratory experiments are needed to demonstrate this point.

Table No. 2

Percent Mortality of Small Larvae in Cambium as Compared to Average Mortality of All Larvae From Same Areas in Bark of Same Thickness

Average Mortality	Mortality of Small Larvae	Increased Mortality Among Small Larvae
38.7 %	100.0 %	158.5%
74.5	100.0	34.2
32.9	88.0	167.5
32.9	100.0	204.0
16.5	100.0	505.0
16.5	43.7	165.0
40.8	100.0	145.0
72.7	100.0	37.5
72.7	100.0	37.5
72.7	100.0	37.5
72.7	96.4	32.6
54.7	100.0	82.9
54.7	100.0	82.9
		130.0 %

Summary

In general, it appears that the weaker larvae of the western pine beetle are fatally affected when the temperature of their immediate environment drops below 10 degrees Fahrenheit and an increasing percentage are killed with further decreases in temperature. Under laboratory conditions practically 100 percent were killed at 18 degrees below zero, and in the field it is probable that none survived bark temperatures of 28 degrees below zero.

Two hours is sufficient duration of any cold temperature to produce mortality in all larvae which are fatally affected by that intensity of cold and no appreciable additional mortality among the more resistant individuals occurs through prolongation of the temperature at that level.

Larvae are adversely affected by moisture under low temperature conditions and small larvae in the cambium layer

are much more susceptible than those in the outer drier bark.

Western pine beetle larvae do not develop resistance to cold through a gradual or alternate lowering of the temperature in any one season, but resistant strains appear to have been developed in the more vigorous portions of their range and in any bark sample resistant individuals are frequently noted.

The Relation of Air Temperature to Bark Temperature

In the previous section we have discussed the effect upon on western pine beetle larvae of direct exposure to lethal low temperatures and have shown that when the temperature of the medium surrounding the larvae drops below 10 degrees a certain percentage of mortality occurs. However, ponderosa pine bark is recognized as a good insulator and before we can determine what the effect of any given air temperature will be in bringing about larval mortality the retarding influence of the bark must be taken into account.

Payne (9), working with the oak borer larvae in 1927, made measurements of the amount of insulation offered by oak bark under which the larvae live and concluded that "the bark offers little absolute insulation, but does not cause the under-bark temperature to lag behind the environmental temperature". This is not in line with the findings in connection with ponderosa pine bark.

The first experiments to determine the relation of air to ponderosa pine bark temperature were conducted by Evenden and Rust in the field in January 1927 and again in January 1928, during periods of sub-zero weather at Coeur d'Alene, Idaho. These were reported by Miller (7). Air temperature dropped to -6° F., while the under bark temperature on the north and south sides of an infested tree were 10 to 12 degrees higher, respectively. No mention was made as to the bark thickness to which these temperatures referred.

In February 1933, Beal and Buckhorn secured a large series of bark temperatures, representing all variations of bark thickness during a period of 66 hours when a new low temperature record for the state of Oregon was established. The results of this work have been covered in detail in a separate report.(4)

Obviously, air temperature has a direct influence upon bark temperature of standing infested pines. Repeated tests have shown that bark temperatures tend to follow the course of air temperature, dropping somewhat more slowly as air temperature goes rapidly down and lagging somewhat behind it as air temperature increases rapidly. Thus there are a number of influences which greatly modify the bark temperature during cold spells.

Apparently the reflection of the sun on the snow has an immediate effect in raising bark temperatures. At nine o'clock on the second day of intensive records the sun shone brightly and all temperatures started rising. On the north side of the trees subcortical temperatures increased rapidly, even though air temperatures remained far below them. This can only be explained by the effect of reflected heat from the sunlight on the snow.

A sharp change in the trend of air temperature produces a corresponding change in subcortical temperatures. An examination of graphs (II) and (III) shows that in thin bark trees there is a lag in bark temperatures behind air temperature of about one hour. (Table 3) In thick bark trees the time of this lag is increased to about two hours. Intermediate bark thicknesses show corresponding lags.

The spread between bark and air temperature is not constant even with bark of one thickness. When air temperature remains at a constant level for the duration of a day or more, bark temperatures tend to reach this level. When air temperatures drop suddenly there is a spread between air and bark temperatures which increases with acceleration of the drop in air temperature and also increases with the bark thickness. As temperatures rise again this spread rapidly disappears until bark and air temperatures are equal and then the spread continues in the other direction until air temperatures again drop below those of the bark.

Table No. 3

Lag and Spread in Air and Bark Temperatures
According to Bark Thickness

Bark Thickness	Air Temp. ° F.	Spread between Air & Bark Temp.	Lag of Bark Behind Air Change
-½"	-26	9 °	1 hr.
5/8-1	-26	18 - 21	1
1-1/8-1½	-26	22 - 27	2
1-5/8-2	-26	26 - 29	2

Graphs (II) and (III) further indicate that the low temperatures obtained during this period would have to be continued for at least 24 hours to bring thick bark down to fatally low temperatures, and there is the possibility that the rate of fall of bark temperatures would slacken if air temperatures remained constant. This is a point upon which additional information should be obtained.

Bark thickness is by far the most important single factor modifying the relation of air temperature to subcortical temperature of trees in the field. A study of the accompanying graphs (II) & (III) shows that temperatures in thin bark trees correspond closely to air temperatures. They cool down rapidly with falling temperatures and warm up quickly as temperatures rise. Temperatures in thick bark trees respond more slowly to changes in air temperature and they require periods of cold of long duration or excessive cold to reach fatal temperatures.

The character of bark probably affects its response to temperature changes; soft spongy bark would appear to be a better insulator than hard flinty bark and as a consequence should offer better protection for the hibernating barkbeetles. During the bark analysis work this difference in bark character and the much higher survival in soft spongy bark was repeatedly noted, but because of the difficulty of classifying bark according to its texture, no statistical data is available to prove or disprove this point. The importance of bark character will be referred to again under the discussion on mortality according to height on the tree.

During the course of the work it was apparent that there was considerable variation in bark temperatures between the north and south sides of the same tree. The south side of the tree warms up rapidly for a short period during the day when the sun is shining directly on the bark. Heat is thus absorbed rapidly and subcortical temperatures rise much higher than those on the north side of the tree. On bright days the sun was found to warm up the south sides of the trees chiefly from about 10 a.m. to 3 p.m. When shadows of other trees interfered, as they frequently did, subcortical temperatures dropped very rapidly. Although the south side of some trees warmed up during the day to as much as 16° F. above air temperature they dropped again during the night as low as subcortical temperatures on the north side of similar trees. While the minimum temperatures reached were practically the same the duration of cold was much greater on the north side of the tree than on the south. Since the north side did not warm up during the middle of the day to the extent that the south side did fatal low temperatures prevailed for a much longer period of time.

This difference was very strikingly shown in a comparison of the percent of mortality from the two sides of a tree. A statistical analysis of the difference of mortality on the north and south sides of 145 trees showed that the mortality on the north side was 30 percent greater than that on the south side (The standard error of this sampling was only 4 percent, so the difference is certainly significant). This higher mortality on the north was in spite of the fact that the bark was found to be on the average one-eighth of an inch thicker on the north than on the south. (This difference in bark thickness appears to be characteristic of ponderosa pines and is probably due to a greater weathering of the south side) The higher mortality on the north side might also be explained by the fact that the cold spell of December was accompanied by a northeast wind which probably tended to chill the north sides of the trees more rapidly than the south side.

The analysis of bark samples showed a very important variation in mortality according to the height on the tree. This is believed to be due largely to a difference in bark character, since the upper bark is more apt to be hard and flinty while basal bark is more spongy. It may also be partly due to a real difference in temperature with colder air in the tree tops than close to the ground.

Western pine beetle brood mortality according to height on trees is summarized according to bark thickness and location in Table (4). This same information is presented in graphic form in graphs (IV), and (V) and (VI).

These data show that between the base and 16 feet there is a wide difference in the amount of winter kill in bark samples of the same thickness. But from 16 to 64 feet above the ground the mortality is practically uniform for each bark thickness from the same areas.

Under such conditions, obviously, the examination of brood samples alone will not give mortality percentages which are accurate for an area.

In order to determine what difference would be reflected in the average mortality percentages, if samples were taken only from the base or included the entire tree, the data from four areas where trees were felled and sampled at intervals along the trunk were summarized in these two ways and the mortality percentages compared. (Table 5)

Table No. 4

Brood Mortality According to Height on Tree

Area Examined	Basal			16'			32'			48'			64'		
	Bark Sq. Ft.	Total Larvae	Percent Killed	Bark Sq. Ft.	Total Larvae	Percent Killed	Bark Sq. Ft.	Total Larvae	Percent Killed	Bark Sq. Ft.	Total Larvae	Percent Killed	Bark Sq. Ft.	Total Larvae	Percent Killed
Bark 1/2" or less															
Ochoco N. F.															
McKay Creek	-	-	-	3.7	547	76.0	4.0	640	91.0	4.1	609	93.4	3.8	458	98.4
Deschutes N. F.		-													
Summit Stage Sta.	-	-	-	2.0	259	100.0	-	200	100.0						
Klamath Indian Res.	-	-	-	-	-	-	1.2	102	97.0						
Deschutes N. F.															
Metolius Area	.6	200	100	-	-	-	1.0	200	99.0				1.0	200	100.0
Bark 5/8-1"															
Ochoco N. F.															
McKay Creek	7.0	1102	42.0	11.7	1745	59.0	11.8	1548	70.2	9.1	1454	65.5	2.2	277	65.5
Deschutes N. F.															
Summit Stage Sta.	7.0	615	76.5	3.2	749	98.0	3.9	855	97.0	3.4	669	100.0	1.2	188	100.0
Deschutes N. F.															
Panhandle Area	3.3	671	83.3	.5	133	100.0									
Klamath Indian Res.	7.0	486	82.0	7.3	2266	92.7	7.3	1693	98.9	6.2	1169	99.4	1.7	400	100.0
Deschutes N. F.															
Metolius	3.7	280	63.2	4.0	978	81.6	3.9	820	78.5	1.8	400	75.0	1.0	200	79.0
Bark 1-1/8-1½"															
Deschutes N. F.															
McKay Creek	7.4	2201	24.2	1.9	358	42.0	1.4	500	59.8						
Deschutes N. F.															
Summit Stage Sta.	9.5	1470	57.5	1.9	468	98.0	.6	200	98.5						
Deschutes N. F.															
Panhandle Area	7.0	2124	74.3	-	-	-	.6	200	89.0	.6	200	97.0	.6	200	98.5
Klamath Indian Res.	15.2	2505	67.0	2.9	300	93.4	-								
Deschutes N. F.															
Metolius	3.0	678	24.2												

Table No. 5

General Average Mortality of the Western Pine Beetle in Total and Basal Bark

Area	Percent Mortality Total Bark	Percent Mortality Basal Bark	Percent Mortality Difference
Ochoco N. F.			
McKay Creek Proj.	53.0	29.5	23.5
Klamath Indian Res.	84.2	69.4	14.8
Deschutes N. F.			
Summit Stage Sta. Proj.	81.0	63.0	18.0
Metolius Area	74.6	52.2	22.4
Total Average			19.7

These figures indicate that the mortality percentage represented by basal sampling is usually from 15 to 20 per cent less than where the entire tree is sampled.

However, the above data is not sufficient, nor the mortality percentages from most areas accurate enough to justify us in raising the mortality percentage on any area by this amount. Further data is needed before such a correction can be applied.

An examination of the preceding table and graphs IV, V and VI shows that in order to obtain more representative figures on mortality of the western pine beetle for any area, it would be preferable to obtain samples somewhat above the base. It is believed that bark samples at about 10 feet would be more representative of both the average bark thickness and the average mortality. Samples above 16 feet show no wide differences in mortality in bark of the same thickness, but instead a rather uniform mortality occurs depending upon air temperature and bark thickness.

Summary

In general it can be said that when air temperatures reach zero degrees Fahrenheit some mortality of western pine beetle broods occurs. Mortality increases with decreased air temperatures but depends largely upon the amount of protection

offered by the bark. Because bark does not cool as rapidly as the air there is often a margin of safety, during extremely cold periods, which enables a portion of the overwintering broods to survive even the most severe cold attained. It is this margin of protection, coupled with the probable ability of these beetles of the more northern range to endure added cold that enables the species to retain its foothold in the northernmost extent of its range.

By projecting the curves in graphs II and III, which depict decreasing bark and air temperatures, it would appear that probably air temperatures of -50 to -60 degrees F. would be required to give bark temperatures of -20 to -25 degrees fatal to all the broods even in bark of two-inch thickness. This point is supported by the fact that low temperatures of -44 degrees F. at Bear Valley resulted in a brood mortality of only 82 per cent (basal samples only). Temperatures low enough to kill all the beetles rarely, if ever, occur in the transition zone of this region.

Conditions Affecting Air Temperature

When low winter temperatures occur over a region it is not the minimum temperature of the entire area which is of most significance in determining beetle mortality but the local minima of very limited areas which must be taken into consideration. Air temperatures undoubtedly vary a great deal in small isolated topographical units. There are a number of local conditions such as exposure, air drainage, cover etc. all of which have an important bearing on the local minima.

The factors affecting local minimum temperatures exert their greatest influence during still, cold, clear nights. (11) Under these conditions the ground cools rapidly through radiation after sun-down and its temperature soon falls below that of the layer of air in contact with it. Air near the ground thus loses heat and becomes cooler and denser than that above and its density keeps it in contact with the ground. Thus over a level plain a thin layer of relatively cold air is formed, while the warmer air seeks the higher levels.

On slopes gravity causes the cold layer of air to flow to lower elevations and gather in depressions somewhat in the same manner as water. In this way temperature inversions are set up in which minima at lower levels are often several degrees lower than those at higher elevations on well drained slopes. Likewise

well rounded summits of low hills are nearly always cooler than the slopes below them on clear calm nights, because of the more effective air drainage on the steeper slopes. Exposure, except as it affects air drainage, would probably not materially affect low minimum temperatures.

It is reasonable to expect that radiation would be greater from exposed areas than from areas where some cover occurred. Temperature in the open therefore probably would be somewhat lower than on similar exposures under some protective covering. Ponderosa pine stands offer only partial cover since openings and large gaps often occur in the timber canopy. Radiation from exposed foliage on clear calm nights is very great and it is well known among orchardists that frost injury frequently occurs in the tops and exposed tree surfaces with no accompanying injury within and beneath the crowns. Under these conditions it may be that in ponderosa pine forests, during cold periods, the tops and upper tree trunks become colder than their basal portions. While this may help to explain the heavier mortality found higher up on the tree trunks, it is a point about which we know very little and its importance should be determined at the earliest opportunity.

A covering of snow on the ground during cold periods would tend to reduce the radiation of heat from the ground to a minimum. Its color as well as its blanket-like effect would aid in decreasing both absorption and radiation of heat.

Humidity has an effect upon the rate at which temperature falls. Other conditions being the same, the temperature falls more slowly when the humidity is high than when it is low.

Air movement has a very significant effect upon local minima. If winds accompany periods of low temperatures then there is a general mixing of the air and the result of the factors affecting local minima becomes obscured and instead of wide local variations more uniform temperatures occur over wider areas. Wind increases radiation from foliage and might thus lower temperatures in the upper crowns and disturb them less below the crowns where the wind would be more or less excluded. Strong winds accompanying cold weather rapidly reduce the temperature of exposed surfaces.

The conditions which prevailed during the freezes of December and February have an important bearing upon the resultant brood mortality. For instance, an abnormally high wind accompanied

the December freeze and throughout the area sampled, thoroughly mixed the air so as to give an evenly distributed and uniform air temperature. The result is that a statistical analysis of the data on brood mortality according to slope and exposure, north, south, east and west slopes, flats, canyons or ridge tops failed to show any significant differences which could be attributed to the exposure factor. Less is known regarding the wind accompanying the February freeze although on the Ochoco Forest some air was continually stirring and in the open it was heavy enough to drift snow across the highways. Since comparatively little wind is necessary to evenly distribute temperatures, it is believed that exposure had little or no effect on mortality during the two freezes of the past winter.

The strong northeast wind which prevailed during the December freeze, apparently did have the effect of chilling the north sides of the trees more completely than the south side, and as the brood mortality figures show the mortality on the north side was fully 30 percent greater than on the south. The warming up of the south side during the day also contributed to this difference in mortality.

During the December freeze the absence of a snow cover greatly increased the effect of radiation and undoubtedly extracted more heat from the trees than would have been the case had there been a snow cover.

The phenomena of increased radiation from the foliage during clear windy nights is known to greatly lower the temperature in tree tops, and may easily result in a lowering of the temperature along the upper bole of the trees through leakage of the warmer air below the crown canopy into the colder air above the forest. This may easily explain why a higher mortality is found in the upper portion of the trunk in bark of the same thickness.

II EXTENSIVE SURVEY DATA

In addition to the detailed studies on the Ochoco, where the effect of known temperatures was studied, bark examinations from a large number of areas throughout eastern Oregon and Washington, when viewed in relation to the low temperatures which prevailed in different parts of the region, throw considerable additional light on the importance of this factor.

The Air Temperatures Which Occurred in the Region

An examination of the official weather records shows a wide variation in the minimum temperatures which actually prevailed in different parts of Oregon and Washington.

During the December 1932 cold spell the lowest temperatures occurred in the open desert country of southeastern Oregon, bordering the Fremont, Deschutes, and Malheur National Forests. Valley Falls reported 54° below; Fremont, 33° below; and Seneca 34°. Timbered areas were much warmer. In Klamath and Lake Counties minima of about 20° below were generally recorded. In the Bend and Metolius region 10° to 15° below was the prevailing temperature. On the Ochoco 15° to 19° below was the general range of minima. On the Columbia River drainage the cold was less severe. Heppner reported only 10° below. Dufur reported -4°.

Eastern Washington was not hit very hard by the December cold spell. The minimum for the state in open hay land was only 14° below and in timbered areas temperatures of from 1 above to 10 below were generally recorded. Subsequent bark examinations showed very little mortality traceable to the December freeze in the state of Washington.

Reference to the accompanying table indicates the minimum temperatures which occurred during the December and February cold spells in both Oregon and Washington.

One of the noteworthy features of the December cold wave was its long duration, lasting as it did from December 7th to the 17th. The coldest day was December 11th, when a temperature of 38 below was recorded at Meacham. This was far from a record (54° below) for the state, but the sustained cold was characterized by the Weather Bureau as "one of the most destructive cold spells in recent history," and "notwithstanding the persistent m mild weather early in the month and after the 18th, the average temperature for the state was the lowest for December since 1924,

Table No. 6

OREGON TEMPERATURES

Station		Type - Environment	Elev.	Minimum Temperatures Dec. 1932	Feb. 1933
Klamath Area					
Klamath Falls	*	Open	4,100	-10°	-10°
Yonna	*	"	4,147	-16°	-16°
Chiloquin	*	Lodgepole-Ponderosa	4,200	-19°	-17°
Klamath Agency	f	Ponderosa		-	-13°
Round Grove	*	Valley Ponderosa Pine	4,888	-20°	
Crater Lake Area					
Sand Creek	*	Lodgepole	4,682	-20°	-33°
Crater Lake	*	Fir-Hemlock	6,475	-90°	-18°
Big Camas	f		3,000	-5°	
Cascade Summit	*	Lodgepole	4,832	-8°	-16°
Lake County Area					
Lakeview	*	Open	4,950	-16°	-22°
Valley Falls	*	"	4,250	-34°	-26°
Parsley	c	"	4,250	-25°	-19°
Fremont	*	"	4,300	-33°	-39°
Pringle Falls					
Crescent		Lodgepole			
Lapine		"			
Fall River	c	"	4,300	-25°	-34°
Metolius Area					
Bend	*	Juniper- S. P.P.	3,629	-10°	-26°
Sisters		Ponderosa		-	-
Montgomery Ranch			1,900	-10°	-20°
Warm Springs	f		1,500	-7°	-17°
Ochoco					
Prineville	*	Open	2,867	-19°	-24°
Ochoco R. S.		Ponderosa Pine		-18°	-26°
Mitchell	*	Juniper	3,766	-16°	-24°
Hay Creek	*	Open canyon	2,938	-15°	-22°

OREGON TEMPERATURES (Cont.)

Station		Type - Environment	Elev.	Minimum Temperatures Dec. 1932	Feb. 1933
Mt. Hood					
Government Camp	c	Fir	3,890	-9°	-11°
Dufur		Open	1,250	-4°	-10°
Malheur Area					
Dayville	•	Open canyon	2,400	-17°	-21°
Prairie City	•	Open valley	3,425	-15°	-31°
Austin	•	Flat valley open Pond.pine	4,200	-28°	-46½°
Seneca	•	Valley Timber near	4,700	-34°	-54°
Bear Valley		Ponderosa		-24°(?)	
Burns (Harney (Exp. Sta.)		Open	4,100	-25°	-38°
Umatilla					
Heppner	•	Open	1,950	-10°	-18°
Kinzua		Ponderosa	3,450	-18°	-31°
Ukiah	•		3,340	-28°	-54°
Wallowa					
Joseph	•		4,400	-25°	-29°
Wallowa	•		2,935	-24°	-38°
Whitman					
Baker	•	Open		-17°	
Minimum for State				-38°	-54°

• -Official Weather Station
c Cooperative " "
f Fire " "

Table No. 7

WASHINGTON TEMPERATURES

Station	Type - Environment	Elev.	Minimum Temperatures Dec. 1932	Feb. 1933
Klickitat				
Goldendale	Open	1,600	-3°	-15°
Bickleton	Open desert	3,000	-3°	-11°
Yakima				
Toppenish	Open agr.	765	-5°	
Wapato	Open agr.	887	-3°	-7°
Yakima	Open flat	1,071	1°	-9°
Rimrock	Canyon - Timber	2,730	-5°	-17°
Tieton Canyon	" "	2,000	-4°	-15°
Naches Heights	Timber	1,874	2°	-12
Bumping Lake	Alpine Type	3,400	-11°	-32°
Wenatchee				
	Edge valley			
Cle Elum	Ponderosa Pine	1,930	-8°	-26°
Lake Kachess	Fir Type	2,270	-4°	-17°
Wenatchee (near)	Scattered pine Hill	2,200	-1°	-13°
Blewett Pass	Timbered - Ponderosa	4,071	-5°	-15°
Leavenworth	Valley cutov. P.Pine	1,350	-10°	-18°
Domke Lake	Pocket - Pine	2,244	3°	-12°
Stehekin (near)	Pine - Canyon	1,150	1°	-10°
Chelan				
	Broad valley			
Stockdill Ranch	Scattered Pond.Pine	2,200	-12°	-30°
Twisp	Deep valley			-30°
Winthrop	" "	1,765	-7°	-27°
Conconully (near)	Forest edge OpenFlat	2,255	-50°	-21
Colville				
Republic	Scattered Timber	2,650		-35°
Chesaw		3,200	-11°	-22
Laurier		1,644	-6°	-24
Kettle Falls (near)	Partly timb.valley	1,265	-4°	-32
Minimum for State			-14°	-40°

and every recording station showed a deficiency in temperature." It is the opinion of some entomologist that this sustained cold was the reason for its effectiveness in bringing about bark beetle mortality. This point will be considered later.

The February 1933 cold spell was of much shorter duration, lasting only two to four days, but was of much greater intensity. A temperature of 54° below was recorded at two stations, setting a new low record for Oregon. It was also more generally distributed throughout eastern Oregon and for the first time this winter affected eastern Washington as well. Since this second cold spell affected Washington areas untouched by the long cold spell of December, we have an opportunity to compare barkbeetle mortality from the two states and determine the relative effectiveness of a long cold spell of moderate intensity as contrasted with a short spell of extreme intensity.

The Proportion of Ponderosa Pine Bark of Varying Thickness

Since it has been shown that bark thickness plays such an important part in modifying brood mortality at any given air temperature, we cannot determine how effective cold weather may be in disposing of western pine beetle broods on any area unless we know how much infested bark there is of various thicknesses. Fortunately it was possible to approximate this proportion from the data already available at the Forest Experiment Station and Forest Insect Station files.

A large series of ponderosa pine stem analysis measurements taken by the Forest Experiment Station men from Site IV and poor Site III gave an opportunity to graph the average bark thickness along the stem of all trees in diameter classes from 10 inches to 50 inches. These averages were based on 240 measured trees. More could have been included but the average from this number appeared to be so consistent that more measurements would have had practically no effect upon the average.

From the plotted stem analysis (See sample graph #VII) it was possible to determine total bark surface for each diameter class and the proportion of this total falling within one-half inch bark thickness groups. The total infested bark, assuming that the infestation reached to an 8-inch top diameter, is shown in Table 8.

The second step was a determination of the frequency distribution of infested ponderosa pines by diameter classes.

This was arrived at in two ways, (1) by tabulation of 13,000 beetle infested trees marked in the southern Oregon surveys; and (2) by tabulation of 3,216 trees treated in the McKay Creek project of the Ochoco. These two frequency curves were so similar that the combined curve can be used as typical of western pine beetle diameter selection in Site IV stands of this region. (graph 8)

In the third step, by multiplying the bark surface for each diameter class by the frequency of infested trees of that diameter class we secure the typical distribution of bark thickness of all infested ponderosa pines on any Site IV area in the region (Table 9).

This table shows that of all infested ponderosa pine bark on a typical Site IV area:

.9% will be ½ inch or less in thickness
67.0% will be from 5/8 to 1 inch in thickness
27.7% will be from 1-5/8 to 1½ inch in thickness
3.6% will be from 1-5/8 to 2 inches in thickness
.8% will be over 2-1/8 inches in thickness

As will be noted only a very small percentage of bark is less than ½ inch in thickness or more than 2 inches; and nearly 95 percent of all bark is from 5/8 to 1½ inch in thickness. Therefore, what happens to beetle broods in bark from 5/8 to 1½ inches thick is of the greatest consequence in determining the total results of a cold spell on any area, and in bark examination the mortality occurring in bark of this thickness should be given a weight corresponding to its importance.

The Brood Mortality Which Occurred in Region Six

When the December cold spell occurred Mr. Jaenicke was in eastern Oregon assisting with the Ochoco control project which was still in progress. Having had experience with beetle mortality in the winter of 1924 on the Metolius, he recognized at once the possible significance of the subzero weather and on the 12th, the day following the coldest day of the month, sent in samples of infested bark from the Orphan Butte area for analysis by the men at this station. These samples were followed by others sent in by Mr. Jaenicke and forest officers from other portions of the Deschutes and Ochoco forests, and were further supplemented with additional samples collected by Messrs. Beal and Buckhorn. In January a large series of samples were collected by Keen and Buckhorn from the McKay Creek project on the Ochoco, and a large series

Table No. 8

Bark Surface of Ponderosa Pine By Diameter and Thickness

D.B.H.	Bark Thickness 0-1/8"	1/8-1/4"	1/4-1/8"	1/8-1/2"	1/2-Over	Total Bark Surface (To 8" Top)
10	-	71	2			73
12	-	85	2			87
14	3	124	3			130
16	6	171	4			180
18	7	208	5			220
20	9	223	20			252
22	9	238	35	6		288
24		240	79	7		326
26		240	120	10		370
28		265	138	12		415
30		250	203	15		468
32		285	215	20		520
34		295	260	25		580
36		310	300	30		640
38		345	320	35		700
40		390	325	45		760
42		20	490	260	50	820
44		550	190	120	20	880
46		300	240	180	240	960
48		40	120	310	520	990
50		150	400	450	80	1080

Table No. 9

Distribution of Bark Surface of Ponderosa Pine
On a Typical Infested Area (Site IV)
By Diameter and Thickness

D.B.H.	Bark Thickness					Site IV % of Diameter Classes	Total Bark Surface (8"Top)
	0-⅜"	5/8 - 1	1-1/8 - 1⅜	1-5/8 - 2	2-1/8 - Over		
10	0	355	10			5.0%	365
12	0	510	12			6.0	522
14	21	868	21			6.9	910
16	38	1300	30			7.6	1368
18	59	1747	42			8.4	1848
20	81	2007	180			9.1	2268
22	88	2332	343	59		910	2822
24		2352	774	69		9.8	3195
26		2136	1068	89		8.9	3293
28		1908	994	86		7.2	2988
30		1425	1187	95		5.7	2667
32		1282	968	90		4.6	2340
34		1091	962	92		3.5	2146
36		775	750	75		2.5	1600
38		621	576	63		1.8	1260
40		468	390	54		1.2	912
42		16	392	208	40	.8	656
44		275	95	60	10	.5	440
46		100	80	60	80	.3	320
48		8	24	62	104	.2	198
50		45	40	15	8	.1	108
Total	237	21,621	8,908	1,167	282	100 %	32,226
Percent	.9	67.0	27.7	3.6	8		100%

of samples were sent in to the laboratory by forest officers from a number of areas in various parts of the region.

These samples were carefully shaved up in the laboratory and the dead and living western pine beetle larvae counted. As far as possible 200 larvae were made the basis for each sample so as to make possible a comparison of averages. Since bark thickness was the most important modifying factor, the counts were tabulated by 5 bark-thickness classes.

The results of these examinations indicating the effectiveness of the December freeze are given in Tables Nos. 10, 11, 12, 15, 18, 22, 25, 30, 35 and 39.

Following the second severe cold spell in February, requests were sent out to the forests for additional samples to determine what its effect had been. Samples were received from many other localities, the largest series coming from the Klamath Indian Reservation, the Metolius area of the Deschutes, the Silver Creek area of the Fremont, and three areas on the Malheur. These also were carefully shaved up and the percent of mortality determined for each area. The results of all examinations to date are given in the following 33 tables.

Accuracy of Mortality Estimates

As might have been expected, the brood counts showed considerable variation in percent of mortality even from samples from the same tree on the same area. It was obvious that examination of small series of samples would give a high probable error, especially as these samples were collected in a variety of ways, and under all sorts of conditions. For instance, some samples were taken only from the basal portion of the trees while others included samples at regular log intervals. Other samples included only thick bark and some came from old beetle abandoned trees. To make the percents of mortality at all comparable the more obvious of these inequalities had to be eliminated.

Bark from beetle abandoned or partly abandoned trees was thrown out and not considered in the averages. Where all thicknesses of bark were represented by the samples from any area, the mortality percentage for each thickness group was multiplied by the percent of its abundance in order to arrive at a weighted average.

BROOD MORTALITY
Western Pine Beetle in Ponderosa Pine
Oregon Examinations

Table No. 10

DESCHUTES NATIONAL FOREST

Summit Stage Station Project - T. 24 S. R. 11 E. Elevation 4800
Samples from 28 trees at breast height and at 16 foot log intervals
Collected Jan 1, 12-20, 1933 by Jaenicke, Beal, Buckhorn and Lynch
Examined Jan. 4 - Feb. 1, 1933 by Beal and Buckhorn
Minimum Temperature Dec. 1932 -30° approx.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-1/8	4	2	0	475	475	237	100%
5/8-1	21	15.0	177	2873	3050	205	94.2
1-1/8-1 1/8	16	11.5	642	1496	2138	186	70.0
1-5/8-2	11	9.3	735	797	1532	165	52.0
2-1/8-Over	2	1.6	177	59	236	147	25.0
Total or Average	54	39.4	1731	5700	7431	188	76.7

Weighted Average - - - - - - - - - - - - - - - - 85.5%

Table No. 11

DESCHUTES NATIONAL FOREST

Panhandle Project Elevation 4500
Samples from 34 trees at breast height and 16 foot log intervals
Collected Jan. 12-20, 1933 by Beal, Buckhorn and Cal, Francis
Examined Jan. 24-31, 1933 by Beal and Buckhorn
Minimum Temperature Dec. 1932 -33° approx.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-1/8	-	-	-	-	-	-	-
5/8-1	10	4.6	159	1375	1534	334	89.5%
1-1/8-1 1/8	20	8.3	792	2080	2872	346	72.5%
1-5/8-2	4	1.9	154	406	560	295	72.5%
2-1/8-Over	6	2.6	717	261	978	376	26.7%
Total or Average	40	17.4	1822	4122	5944	342	69.4%

Weighted Average - - - - - - - - - - - - - - - - 83.7%

BROOD MORTALITY
Western Pine Beetle in Ponderosa Pine
Oregon Examinations

Table No. 12

DESCHUTES NATIONAL FOREST

Metolius Area - T. 13 S. R. 9 E. Elevation 3000 3400
Samples from 6 trees at breast height and 16 foot log intervals
Collected Jan. 11, 1933 by Beal and Buckhorn
Examined Jan. 24, 1933 by Beal and Buckhorn
Minimum Temperature Dec. 1932 -12°

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-1/8	4	4.0	2	798	800	200	99.8%
5/8-1	13	12.5	488	1990	2478	193	80.4
1-1/8-1½	3	3.1	514	164	678	219	24.2
1-5/8-2	1	.6	192	8	200	333	4.0
2-1/8-Over	-	-	-	-	-	-	
Total or Average	21	20.2	1196	2960	4156	206	71.2
Weighted Average - - - - - - - - - - - - - - - -							62.6%

Table No. 13

DESCHUTES NATIONAL FOREST

Metolius Area - T. 12-13 S. R. 9 E. Elevation 3000 - 3400
Samples from 52 trees at breast height
Collected March 5, 1933 by Ranger R. P. McReynolds
Examined March 10-16, 1933 by Buckhorn and Lynch
Minimum Temperature Dec. 1932 -12° Feb. 1933 -22°

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-1/8	-	-	-	-	-	-	-
5/8-1	20	17.5	1532	1643	2975	170	55.3%
1-1/8-1½	26	22.0	2739	1443	4182	190	34.5%
1-5/8-2	4	3.6	441	187	628	175	29.8
2-1/8-Over	-	-	-	-	-	-	-
Total or Average	50	43.1	4512	3273	7785	181	42.1
Weighted Average - - - - - - - - - - - - - - - -							48.4%

BROOD MORTALITY
Western Pine Beetle in Ponderosa Pine
Oregon Examinations

Table No. 14

DESCHUTES NATIONAL FOREST

Metolius Area - T. 12 & 13 S. R. 9 E. Elevation 2700 - 3200
Samples collected March 24-25, 1933 from 30 trees - all basal
Examined March 29, 1933 by Lynch. Collected by Ranger McReynolds
Minimum Temperatures - Dec. 1932 -12°F, Feb. 1933 -22°F.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-⅜	1	.3	3	64	67	223	95.5%
5/8-1	14	8.8	617	646	1263	144	51.1
1-1/8-1⅜	11	6.9	937	593	1530	221	38.7
1-5/8-2	4	215	331	168	499	200	33.7
2-1/8-Over	-	-	-	-	-	-	-
Total or Average	30	18.5	1888	1471	3359	181	43.8

Weighted Average - - - - - - - - - - - - - - - 47.3%

Table No. 15

FREMONT NATIONAL FOREST

Quartz Butte Area - T. 37 S. R. 16 E. Sec. 26 Elevation 5300 - 5500
Samples from 6 trees N. and S. side at breast height
Collected Jan. 20, 1933 by Walt Perry (?)
Examined Feb. 3, 1933 by Beal and Buckhorn
Minimum Temperature Dec. 1932 -20°F.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-⅜"	-	-	-	-	-	-	-
5/8-1	-	-	-	-	-	-	-
1-1/8-1⅜	4	3.0	351	391	742	248	52.7
1-5/8-2	7	6.4	932	468	1400	219	33.4
2-1/8-Over	-	-	-	-	-	-	-
Total or Average	11	9.4	1283	859	2142	228	40.1

Estimated Weighted Average - - - - - - - - - - 67.5%

BROOD MORTALITY
Western Pine Beetle in Ponderosa Pine
Oregon Examinations

Table No. 16

FREMONT NATIONAL FOREST

Quartz Valley Area - T. 37 S. R. 16 E. Elevation 4800 - 5600
Samples from 13 trees - all basal
Collected about March 26, 1933
Examined March 30, 1933 by Lynch
Minimum Temperatures - Dec. 1932 -28°, Feb. 1933 -26°(?)

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-1/8	-	-	-	-	-	-	-
5/8-1	8	2.3	63	387	450	196	86.0
1-1/8-1½	8	5.0	404	677	1081	216	62.6
1-5/8-2	-	-	-	-	-	-	-
2-1/8-Over	-	-	-	-	-	-	-
Total or Average	13	7.3	467	1064	1531	210	69.4

Estimated Weighted Average - - - - - - - - - - - - 80.0%

Table No. 17

FREMONT NATIONAL FOREST

Silver Creek Area - T. 29 S. R. 12-13-14 E. Elevation - 4600
Samples from 20 trees taken at breast height
Collected March 2-4, 1933 by Ranger L. O. Bailey
Examined March 14, 1933 by Buckhorn and Lynch
Minimum Temperatures - Dec. 1932 -30° approx., Feb. 1933 -36° approx.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-⅛"	-	-	-	-	-	-	-
5/8-1	3	1.7	180	291	471	277	61.8%
1-1/8-1½	9	5.5	300	1266	1566	285	80.8
1-5/8-2	6	2.7	341	558	899	333	62.1
2-1/8-Over	-	-	-	-	-	-	-
Total or Average	18	9.9	821	2115	2936	296	72.0

Estimated Weighted Average - - - - - - - - - - - - 84.0

BROOD MORTALITY
Western Pine Beetle in Ponderosa Pine
Oregon Examinations

Table No. 18

KLAMATH INDIAN RESERVATION

Modoc Point - T. 36 S. R. 8 E. Elevation 5000
Samples taken from 3 trees at 16' log intervals
Collected Jan. 26, 1933 by H. A. Kallendar
Examined Feb. 1933 by Buckhorn and Whiteside
Minimum Temperature Dec. 1932 -19°F.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-1/8"	-	-	-	-	-	-	-
5/8-1	17	19.8	193	3110	3303	167	94.2%
1-1/8-1 1/2	2	2.3	224	176	400	174	44.0
1-5/8-2	-	-	-	-	-	-	-
2-1/8-Over	1	.9	64	136	200	222	68.0
Total or Average	20	23.0	481	3422	3903	170	87.8
Estimated Weighted Average - - - - - - - - - - - -							83.0%

Table No. 19

KLAMATH INDIAN RESERVATION

Samples from 9 trees taken at 16' intervals and N. & S. Sides
Collected about March 8, 1933 by Harold Weaver
Examined March 17-23, 1933 by Buckhorn, Lynch and Nogero
Minimum Temperatures - Dec. 1932 -19°, Feb. 1933 -25°

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-1/8	1	1.3	4	98	102	78	96.0%
5/8-1	20	28.3	89	3129	3218	114	97.2
1-1/8-1 1/2	12	19.2	615	1681	2296	119	73.3
1-5/8-2	4	3.5	124	485	609	174	79.6
2-1/8-Over	-	-	-	-	-	-	-
Total or Average	37	52.3	832	5393	6225	119	86.7
Weighted Average - - - - - - - - - - - - - - -							89.8%
Basal Samples only - - - - - - - - - - - - - -							82.7%

BROOD MORTALITY
Western Pine Beetle in Ponderosa Pine
Oregon Examinations

Table No. 20

LONG BELL RESERVATION TRACT

Lamm Lumber Co. Area - T. 31 S. R. 11 E.
Samples from 20 trees at breast height
Collected about March 26, 1933 by Chas. W. King
Examined April 1-3, 1933 by Lynch
Minimum Temperatures: Dec. 1932 -20°F., Feb. 1933 -26°F.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-⅛	1	.5	0	86	86	172	100%
5/8-1	7	3.6	38	350	388	108	90.2
1-1/8-1⅛	9	4.5	516	560	1076	239	52.1
1-3/8-2	3	1.6	191	331	522	326	63.3
2-1/8-Over	-	-	-	-	-	-	-
Total or Average	20	10.2	745	1327	2072	203	64.0
Weighted Average - - - - - - - - - - - - - - - -							78.5

Table No. 21

LONG BELL RESERVATION TRACT

Long Bell Area - T. 32 S. R. 11 E.
Samples from 20 trees at near base
Collected about March 26, 1933 by Chas. W. King
Examined March 31-April 3, 1933 by Lester Lynch
Minimum Temperatures: Dec. 1932 -20°F., Feb. 1933 -26°F.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-⅛	-	-	-	-	-	-	-
5/8-1	4	2.0	92	286	378	189	75.6%
1-1/8-1⅛	12	5.1	626	813	1439	282	56.5
1-5/8-2	4	1.9	339	214	553	291	38.7
2-1/8-Over	-	-	-	-	-	-	-
Total or Average	20	9.0	1057	1313	2370	263	55.4
Weighted Average - - - - - - - - - - - - - - - -							68.6%

BROOD MORTALITY
Western Pine Beetle in Ponderosa Pine
Oregon Examinations

Table No. 22

MALHEUR NATIONAL FOREST

Bear Gulch and Officer Creek - T. 15-17 S. R. 29-31 E. Elevation 4600-5400
Samples taken from 13 trees at breast height
Collected about Jan. 24, 1933 by Ranger Elliott
Examined Feb. 10, 1933 by Buckhorn and Whiteside
Minimum Temperature Dec. 1932 -24°F. approx.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-1/8"	-	-	-	-	-	-	-
5/8-1	2	1.24	111	147	258	208	57.0%
1-1/8-1 1/8	6	5.42	666	361	1027	190	35.2
1-5/8-2	4	6.30	605	98	703	112	13.9
2-1/8-Over	1	1.92	164	36	200	104	18.0
Total or Average	13	14.88	1546	642	2188	147	29.3

Estimated Weighted Average - - - - - - - - - - - - 48.0%

Table No. 23

MALHEUR NATIONAL FOREST

Burns Area - T. 22 S. R. 28 E. Sec. 22 Elevation 5000
Samples from 12 trees at breast height
Collected Feb. 5, 1933 by Ranger M. O. Timms
Examined Feb. 14, 1933 by Buckhorn and Whiteside
Minimum Temperature Dec. 1932 -24°F. approx.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-1/8"	-	-	-	-	-	-	-
5/8-1	-	-	-	-	-	-	-
1-1/8-1 1/8	-	-	-	-	-	-	-
1-5/8-2	8	12.3	1064	481	1545	126	31.1
2-1/8-Over	-	-	-	-	-	-	-
Total or Average	8	12.3	1064	481	1545	126	31.1

Estimated Weighted Average - - - - - - - - - - - - 62.0%

BROOD MORTALITY
Western Pine Beetle in Ponderosa Pine
Oregon Examinations

Table No. 24

MALHEUR NATIONAL FOREST

Burns Area - T. 20 S. R. 31 E. Elevation 4800-5350
Samples from 31 trees taken on N. and S. side near base
Collected about March 29, 1933 by Ranger M. C. Timms
Examined April 11-13, 1933 by Lynch and Whiteside
Minimum Temperatures Dec. 1932 -24°F., Feb. 1933 -35°F.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-½"	-	-	-	-	-	-	-
5/8-1	6	2.3	48	397	445	194	89.2%
1-1/8-1½	17	7.2	233	1261	1494	208	84.4
1-5/8-2	20	11.7	599	1268	1867	160	67.9
2-1/8-Over	3	1.4	194	278	472	337	58.8
Total or Average	46	22.6	1074	3204	4278	189	75.0
Weighted Average - - - - - - - - - - - - - - - -							86.9%

Table No. 25

MALHEUR NATIONAL FOREST

Bear Valley Sale Area - T. 15-16 S.R. 30-31 E. Elevation 4500-5300
Samples from 25 trees taken on N. and S. side near base
Collected March 26-29, 1933 by F. W. Cory
Examined April 4-6, 1933 by Lynch and Whiteside
Minimum Temperatures: Dec. 1932 -24°F., Feb. 1933 -44°F.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-½"	2	-	-	-	-	-	-
5/8-1	51	30.5	515	4863	5378	176	90.3%
1-1/8-1½	28	15.7	1175	2481	3656	233	67.9
1-5/8-2	9	8.0	472	850	1322	166	64.2
2-1/8-Over	1	.4	163	46	209	523	22.0
Total or Average	36	54.6	2325	8240	10565	193	78.0
Weighted Average - - - - - - - - - - - - - - - -							82.6%

BROOD MORTALITY
Western Pine Beetle in Ponderosa Pine
Oregon Examinations

Table No. 26

MALHEUR NATIONAL FOREST

South Fork John Day Area - T. 17-19 S. R. 28-29 E. Elevation 4000-5600
Samples from 36 trees taken on N. and S. sides near base
Collected about April 2, 1933 by Ranger H. R. Elliott
Examined April 15-17, 1933 by Lynch and Whiteside
Minimum Temperatures: Dec. 1932 -24°F., Feb. 1933 -44°F.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-½ "	2	1.0	0	115	115	115	100 %
5/8-1	13	6.0	73	948	1021	170	92.8
1-1/8-1½	27	13.4	652	2267	2919	218	77.7
1-5/8-2	17	9.0	987	1505	2592	288	61.9
2-1/8-Over	6	3.3	401	361	762	231	47.4
Total or Average	65	32.7	2113	5296	7409	227	71.4

Weighted Average - - - - - - - - - - - - - - - 86.4%

Table No. 27

MALHEUR NATIONAL FOREST

Murderers Creek Area - T. 15 S. R. 29 E. Elevation 3400-5200
Samples from 35 trees taken on North and E. side near base
Collected about April 2, 1933 by Ranger H. R. Elliott
Examined April 13-15, 1933 by Lynch and Whiteside
Minimum Temperatures: Dec. 1932 -24, Feb. 1933 -44 °F.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-⅜ "	4	-	-	-	-	-	-
5/8-1	10	4.2	94	1212	1306	311	92.8
1-1/8-1½	30	12.6	952	2504	3456	274	72.4
1-5/8-2	11	4.7	592	795	1387	295	57.3
2-1/8-Over	2	1.0	294	67	361	361	18.6
Total or Average	53	22.5	1932	4578	6510	289	70.4

Weighted Average - - - - - - - - - - - - - - - 85.3%

BROOD MORTALITY
Western Pine Beetle in Ponderosa Pine
Oregon Examinations

Table No. 28

MT. HOOD NATIONAL FOREST

Wapinitia Area - T. 5 S. R. 11 E. Elevation 3300
Samples from 11 trees
Collected March 18, 1933 by Ranger O. J. Johnson
Examined March 24, 27, 1933 by Lynch
Minimum Temperatures: Dec. 1932 -6°F., Feb. 1933 -12°F.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-1/8"	-	-	-	-	-	-	-
5/8-1	5	3.4	91	96	187	55	51.4%
1-1/8-1½	4	3.4	156	194	350	103	55.5
1-5/8-2	2	1.3	168	66	234	180	28.2
2-1/8-Over	-	-	-	-	-	-	-
Total or Average	11	8.1	415	356	771	95	46.2
Estimated Weighted Average - - - - - - - - - - -							61.0%

BROOD MORTALITY
Western Pine Beetle in Ponderosa Pine
Oregon Examinations

Table No. 29

OCHOCO NATIONAL FOREST

Snow Mountain Area - T. 22 S. R. 28 E. Elevation 4950-5200
Samples from 58 trees taken on North and South side near base
Collected about March 30, 1933 by Ranger M. O. Timms
Examined April 11-13, 1933 by Lynch and Whiteside
Minimum Temperatures: Dec. 1932 -24°F.. Feb. 1933 -35°F.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-½"	2	.6	0	61	61	102	100 %
5/8-1	10	3.5	96	530	626	179	8417
1-1/8-1½	38	15.3	605	1619	2224	145	72.7
1-5/8-2	31	11.8	1090	1317	2407	204	54.7
2-1/8 -Over	20	9.7	1043	627	1670	172	37.5
Total or Average	101	40.9	2834	4154	6988	170	59.5
Weighted Average - - - - - - - - - - - - - -							79.2%

Table No. 30

OCHOCO NATIONAL FOREST

McKay Creek Project - T. 12 S. R. 16 E. Elevation 4000
Samples taken from 85 trees at breast height and at 10' log intervals
Collected Jan. 1-25, 1933 by Jaenicke, Keen and Buckhorn
Examined Jan. 24- Feb. 25, 1933 by Beal and Buckhorn
Minimum Temperature Dec. 1932 -21°F.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-⅝"	24	16.8	321	2126	2447	145	86.9%
5/8-1	74	55.2	3393	6592	9985	181	66.0
1-1/8-1½	50	34.1	4350	3222	7572	222	41.3
1-5/8-2	15	7.8	3593	1236	4829	619	25.6
2-1/8-Over	1	.3	100	35	135	450	25.9
Total or Average	164	114.2	11757	13211	24968	219	53.0
Weighted Average - - - - - - - - - - - - - -							57.6%

BROOD MORTALITY
Western Pine Beetle in Ponderosa Pine
Oregon Examinations

Table No. 31

OCHOCO NATIONAL FOREST

Maury Mt. Area - T. 17, 18 S. R. 18, 20 E. Elevation 3800-4500
Samples from 22 trees on N. and S. side near base
Collected by Rangers Wirth and Rector about April 2, 1933
Examined April 13-15, 1933 by Lynch and Whiteside
Minimum Temperatures: Dec. 1932 -21°F., Feb. 1933 -26°F.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-½"	1	.5	0	76	76	152	100 %
5/8-1	6	2.7	215	235	450	167	52.3
1-1/8-1½	25	11.2	1135	1557	2490	222	54.5
1-5/8-2	9	4.2	487	452	939	225	48.2
2-1/8-Over	-	-	-	-	-	-	-
Total or Average	41	18.6	1835	2120	3955	213	53.6
Weighted Average - - - - - - - - - - - - - - -							52.3%

Table No. 32

OCHOCO NATIONAL FOREST

Snow Mt. Area - T. 19 S. R. 25 E. Elevation 4350-5500
Samples from 26 trees on N. & S. side near base
Collected by Rangers Wirth and Rector about April 1, 1933
Examined April 13-15, 1933 by Lynch and Whiteside
Minimum Temperatures: Dec. 1932 -24°F., Feb. 1933 -36°F.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-½	-	-	-	-	-	-	-
5/8-1	7	2.8	11	572	583	208	98.2 %
1-1/8-1½	22	10.5	343	1321	1664	158	79.4
1-5/8-2	11	4.9	250	533	783	160	68.0
2-1/8-Over	5	2.6	89	297	386	149	76.9
Total or Average	45	20.8	693	2723	3416	164	79.8
Weighted Average - - - - - - - - - - - - - - -							91.9%

BROOD MORTALITY
Western Pine Beetle in Ponderosa Pine
Oregon Examinations

Table No. 32

ROGUE RIVER NATIONAL FOREST

Keno Pinehurst Area - T. 39, 40 S. R. 4, 5, 7½E. Elevation 4100-4600
Samples from 25 trees on N. & S. side near base
Collected April 6, 1933 by Ranger J. G. Elgan
Examined April 8-10, 1933 by Lynch and Whiteside
Minimum Temperatures: Dec. 1932 -10°F., Feb. 1933 -10°F.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-½"	-	-	-	-	-	-	-
5/8-1	8	5.6	605	314	919	164	34.2%
1-1/8-1½	21	13.0	1767	866	2633	202	32.9
1-5/8 -2	13	9.5	1427	380	1807	190	21.0
2-1/8-Over	5	3.4	652	199	851	250	23.4
Total or Average	47	31.5	4451	1759	6210	197	28.3
Weighted Average -- - - - - - - - - - - - -							32.5%

BROOD MORTALITY
Western Pine Beetle in Ponderosa Pine
Oregon Examinations

Table No. 34

UMATILLA NATIONAL FOREST

Ditch Creek Area - T.7-8 S. R.24-25 E. Elevation 3200-4200
Samples from 27 trees taken on N. & S. side
Collected about April 5, 1933 by F. D. Monroe
Examined April 7-10, 1933 by Lynch and Whiteside
Minimum Temperatures: Dec. 1932 -14°F., Feb. 1933 -25°F. approx.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-⅛	-	-	-	-	-	-	-
5/8-1	10	5.4	431	524	955	177	54.8
1-1/8-1⅛	23	13.5	1670	1280	2950	218	43.4
1-5/8-2	10	5.4	319	436	755	140	57.7
2-1/8-Over	7	3.8	722	218	940	247	23.2
Total or Average	50	28.1	3142	2458	5600	200	43.8

Weighted Average - - - - - - - - - - - - - - 51.8%

Table No. 35

UMATILLA NATIONAL FOREST

Heppner Area - T. 5 S.R. 26 E. Sec. 19-30; T. 4 S.R. 27 E. Sec. 27-28-34
Samples from 15 trees at breast height Elevation 3500-3800
Collected about Jan. 28, 1933 by Ranger P. F. Wehmeyer
Examined Feb. 10, 1933 by Buckhorn and Whiteside
Minimum Temperature Dec. 1932 -14°F.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-⅛ "	-	-	-	-	-	-	-
5/8-1	9	5.6	605	314	919	164	34.2%
1-1/8-1⅛	8	6.34	917	258	1175	185	21.9
1-5/8-2	2	1.75	282	118	400	228	29.5
2-1/8-Over	2	2.24	249	23	272	121	8.5
Total or Average	13	12.10	1478	549	2027	168	27.1

Weighted Average - - - - - - - - - - - - - - 38.0%

BROOD MORTALITY
Western Pine Beetle in Ponderosa Pine
Oregon Examinations

Table No. 36

WHITMAN NATIONAL FOREST

Unity Area - T. 13,14 S. R. 36 E. Elevation 4100-5100
Samples from 14 trees at base
Collected March 31 and April 3, 1933 by Ranger George Palmer
Examined April 4-6, 1933 by Lynch and Whiteside
Minimum Temperatures: Dec. 1932 -17°F., Feb. 1933 -35°F.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae Per Sq. Ft.	Percent Killed
0-½	2	.7	0	146	146	209	100 %
5/8-1	6	2.2	113	329	442	201	74.5
1-1/8-1½	11	3.5	484	343	827	236	41.5
1-5/8 -2	4	1.2	152	96	248	206	38.7
2-1/8 -Over	2	.9	114	97	211	234	46.0
Total or Average	25	8.5	863	1011	1874	221	53.9

Weighted Average - - - - - - - - - - - - - - 63.3%

BROOD MORTALITY
Western Pine Beetle in Ponderosa Pine
Washington Examinations

Table No. 57

CHELAN NATIONAL FOREST

Twisp - Winthrop Area - T. 33-36 N. R. 21 E. Elevation 1900-2800
Samples from 8 trees at breast height
Collected Feb. 25, 1933 by Ranger Burge
Examined Feb. 28-March 1, 1933 by Buckhorn and Lyndh
Minimum Temperatures: Dec. 1932 -7°F., Feb. 1933 -27°F.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-1/8"	-	-	-	-	-	-	-
5/8-1	3	3.8	32	23	55	14	41.8%
1-1/8-1½	3	3.9	201	106	307	79	34.5
1-5/8-2	2	2.2	97	169	266	121	63.5
2-1/8-Over	-	-	-	-	-	-	-
Total or Average	8	9.9	330	298	628	63	47.5%
Weighted Average - - - - - - - - - - - - - - - -							77.0%

Table No. 58

COLVILLE NATIONAL FOREST

Tonasket Area - T. 35 N. R. 30 E. Sec. 25 Elevation 2700
Samples from 7 trees at breast height
Collected about March 10, 1933 by Ranger P. K. Taylor
Examined March 17, 1933 by Buckhorn and Lynch
Minimum Temperatures: Dec. 1932 -5°F. approx., Feb. 1933 -35°F. approx.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-1/8	-	-	-	-	-	-	-
5/8-1	-	-	-	-	-	-	-
1-1/8-1½	1	.76	101	99	200	263	49.5%
105/8-2	2	2.59	252	167	419	162	39.8
2-1/8-Over	1	.97	138	63	201	207	32.3
Total or Average	4	4.32	491	329	820	190	40.1
Estimated Weighted Average - - - - - - - - - - - -							30.0%

BROOD MORTALITY
Western Pine Beetle in Ponderosa Pine
Washington Examinations

Table No. 39

KLICKITAT COUNTY

Eastern and Western Lumber Company tract - T. 5 N. R. 14-16-17-19 E.
Samples taken from 9 trees at 8 to 9 feet above ground — Elevation 2000-3000
Collected about Jan. 22, 1933 by Mr. C. E. Blanchard
Examined Feb. 3, 1933 by Buckhorn and Whiteside
Minimum Temperature Dec. 1932 -3°F.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-1/2	-	-	-	-	-	-	-
5/8-1	3	6.3	1159	108	1266	186	8.5%
1-1/8-1 1/2	7	6.8	683	87	770	113	11.3
1-5/8-2	2	2.2	382	18	400	182	4.5
2-1/8-Over	-	-	-	-	-	-	-
Total or Average	17	15.8	2223	213	2436	154	8.8

Weighted Average - - - - - - - - - - - - - - - - 10.4%

Table No. 40

KLICKITAT COUNTY

Eastern & Western Lumber Company tract - T. 5 N. R. 14-16 E. — Elevation 2000-3000
Samples from 5 trees taken at 8-9 feet above ground
Collected March 8, 1933 by Mr. C. E. Blanchard
Examined March 16, 1933 by Buckhorn and Lynch
Minimum Temperatures Dec. 1932 -3°, Feb. 1933 -13°F.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-1/2	1	1.0	25	73	99	99	73.8%
5/8-1	3	1.8	215	148	363	202	40.8
1-1/8-1 1/2	9	7.4	496	330	826	102	40.0
1-5/8-2	3	2.8	285	132	417	149	31.7
2-1/8-Over	-	-	-	-	-	-	-
Total or Average	16	13.0	1022	683	1705	131	40.0

Weighted Average - - - - - - - - - - - - - - - - 40.5%

BROOD MORTALITY
Western Pine Beetle in Ponderosa Pine
Washington Examinations

Table No. 41

WENATCHEE NATIONAL FOREST

Leavenworth Station - T. 22-24-25 N. R. 17-18 E. Elevation
Samples taken from 7 trees at breast height 1800-2600
Collected Feb. 2-3, 1933 by P. A. Brinson
Examined March 6, 1933 by Buckhorn and Lynch
Minimum Temperature Dec. 1932 -1°F.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-1/8	-	-	-	-	-	-	-
5/8-1	-	-	-	-	-	-	-
1-1/8-1 1/8	3	7.6	247	7	254	33	2.8
1-5/8-2	4	10.3	518	16	534	52	3.0
2-1/8-Over	-	-	-	-	-	-	-
Total or Average	7	17.9	765	23	788	44	2.9

Weighted Average - - - - - - - - - - - - - - - - 5.0%

Table No. 42

WENATCHEE NATIONAL FOREST

Entiat Area - T. 26,27,28 N. R. 19, 20 E. Elevation
Samples from 25 trees taken on N. and S. sides near base 1400-5100
Collected about March 31, 1933 by Ranger Glenn C. Charlton
Examined April 4-6, 1933 by Lynch and Whiteside
Minimum Temperatures: Dec. 1932 -4°F., Feb. 1933 -14°F.

Bark Thickness	No. Samples	No. Sq. Ft.	Western Pine Beetle Larvae: Living	Dead	Total	Total Larvae: Per Sq. Ft.	Percent Killed
0-1/8	3	1.2	22	4	26	22	15.4%
5/8-1	6	2.7	114	41	155	57	26.4
1-1/8-1 1/8	14	7.1	580	200	780	110	25.6
1-5/8-2	11	5.4	1149	227	1376	255	16.5
2-1/8-Over	5	2.3	641	106	747	325	14.2
Total or Average	39	18.7	2506	578	3084	165	18.7

Weighted Average - - - - - - - - - - - - - - - - 25.6%

From areas having a large series of samples, it was found that the percent of mortality in any bark thickness group bore a definite relation to the average mortality. Thus the mortality in bark of 0-½ inch in thickness was 143 percent of the average; the mortality in bark 5/8-1 inch thick was 107 percent of the average; the mortality in bark 1-1/8 to 1½ inch thick was 82 percent of the average; in bark 1-5/8 to 2 inches thick 62 percent of the average; and in bark 2-1/8 inches and over 47 percent of the average.

Therefore, in samples which included only one to three of the five bark thickness groups, these ratios could be used to determine an approximation of the weighted average.

The conversion factors were as follows:

Table 43

Bark Thickness Group								
0-½"	Percent mortality for group	x	.70	=	Weighted average mortality			
5/8-1	"	"	"	"	x	.93	=	"	"
1-1/8-1½	"	"	"	"	x	1.22	=	"	"
1-5/8-2	"	"	"	"	x	1.62	=	"	"
2-1/8-Over	"	"	"	"	x	2.12	=	"	"

Wherever the sample was adequate, 200 larvae were counted as representative of the mortality for that particular location on the tree; and as many different locations were examined as the material permitted. It was very evident from the bark examinations that brood mortality was very variable even from one locality, bark thickness and location on the tree, and that the standard deviation of mortality percent was high.

The percent of mortality from 35 samples from the Ochoco, taken at 16 feet or higher on the tree with bark between 5/8 and 1 inch in thickness, showed a standard deviation of 22.3 percent; and a maximum error of the mean of about 11 percent. To keep

the maximum error of the mean within 10 percent would require the examination of 45 samples, or approximately 9000 larvae. In most of the samples fewer larvae than this were counted and the standard error was correspondingly higher.

The Relation of Brood Mortality to Local Air Temperatures

Miller determined the bark temperatures which were fatal to western pine beetle under laboratory conditions. In the February freeze Beal determined the relation of air to bark temperatures and secured a limited amount of data as to the percent of brood mortality which actually occurs at various bark temperatures under field conditions. The comparison of laboratory and field records is shown in Graph 1. Evidently under field conditions these beetles are able to withstand lower temperatures than under the artificial conditions set up in the laboratory.

Under field conditions, it is most important to know what effect a given air temperature will have upon brood mortality. It is therefore of interest to compare the known air temperatures from the nearest official weather station to the average brood mortality which occurred nearby. This comparison is shown in Graph 9.

There are several factors which impair the accuracy of this comparison. In the first place, the air temperatures at the nearest official station may be quite different from the temperatures which actually existed in the woods. Usually the weather station is in a valley, near a town, or in open agricultural land. In only rare cases are stations actually located in the forests. In the second place the percent of mortality is subject to the errors of sampling and in some cases this is very high due to the small number of samples involved.

Nevertheless, the relationship of the official air temperatures to the mortality which occurred is apparent and surprisingly consistent. At an air temperature of 0 degrees mortality commenced and reached 85 percent with an air temperature of 32 degrees below. Moreover this curve parallels the one determined by Beal for fatal bark temperatures and at an interval of about 10 degrees below it. In other words, on the average there is a 10 degree spread between air and bark temperatures producing equal brood mortality. If this relationship is found to be reliable after further field test, it will be of immense value in future years. Without further examination it will be possible to say that if air temperatures reach 20 degrees below zero for a period

of at least two hours over 50 percent of western pine beetle brood will be killed in any ponderosa pine Site IV stand. If the temperature drops to 28 below, 75 percent will be killed and for any other temperature the mortality percent can be readily estimated. This is one of the final objectives of studies such as this, but it is not claimed that the present relationship as shown in Graph 9 can be accepted as final. It is very suggestive and is certainly close to the final figure, but will require further verification in other localities and other years.

Importance of Duration of Cold Weather

Several persons have attributed the effectiveness of the December 1932 cold spell in causing beetle mortality to its long duration, since it lasted ten days (from December 7th to 17th). It was also accompanied by an east wind which tended to chill the bark down to somewhere near air temperature. On the other hand, there was a daily fluctuation with maximum temperatures ranging from zero to 28 degrees above. Thus the trees had a chance to warm up each day, but in some cases undoubtedly remained at subzero temperatures for 12 hours or more. The effectiveness of this kill has been shown in preceding graphs.

On the other hand, the February freeze was of short duration. Air temperature dropped rapidly from near freezing to 26 or 36 below for one night and then came back to above zero during the day. As Beal's records show, bark temperatures dropped much more slowly than air temperatures, and since the lows were of short duration, bark temperatures never came within 8 degrees of air temperature even for thin bark and were 29 degrees higher for thick bark. Under such conditions, with low temperatures of short duration, fatal lows would not be reached to the same extent as for a longer period and hence we would not expect such general heavy mortality.

In Washington the short February cold spell was the only one this winter to cause any appreciable beetle mortality, but the indications are that the minima reached in February gave approximately as high a mortality as similar minima in the December freeze in Oregon. This would indicate that the duration of the cold was not as important as its intensity. However, the number of Washington bark examinations are not sufficient as yet to prove this point conclusively. Additional bark examinations later this year should throw more light on this point.

III. INTERPRETATION OF BEETLE MORTALITY IN RESPECT TO PAST EPIDEMICS

The fact that low temperatures may cause widespread western pine beetle mortality at once raises the question as to its importance in controlling barkbeetle outbreaks. If low temperatures can be counted upon to wipe out epidemics there would appear to be little reason for spending large sums in control work.

Frequency of Sub-Zero Weather in the Pine Region

The general impression is that sub-zero weather is a regular occurrence in the pine region of eastern Oregon and Washington. But an examination of the weather records shows that this is not the case. While sub-zero weather does occur every year in eastern Oregon, such records apply to farming valleys and are not typical of the pine beetle region. Table 44 gives a record of the minima for southern Oregon stations near the pine belt since 1915, and also the mean and minimum temperatures for eastern Oregon as a whole. These mean and minimum temperatures for January and December of each year, and February temperatures in cases where they are the lowest, are shown in graph 10. Apparently extremely low temperatures occur at intervals of about three years. Since 1915 exceptionally cold spells have occurred as follows:-

Month & Year	Weather Bureau Comment
January 1917	Snow on the ground alternate freezing and thawing. Wheat was injured.
December 1919	Snow on the ground. Wheat escaped injury.
January 1922	Cold and dry. Coldest month on record except for 1916 (mean). Snow on the ground. Wheat not injured.
December 1924	Coldest December on record (since 1890). Longest and most severe cold spell experienced in Oregon. Snowfall light. Much injury to winter wheat.
January 1927	Unusually low temperatures. Some records broken. Heavy snow accumulation. No damage to wheat.
February 1929	Coldest February in Oregon since records begun. Dry but snow in the mountains. Wheat suffered little.

Minimum Temperatures
Eastern Oregon
1915-1933

TABLE No. 44

Station	15-16		16-17		17-18		18-19		19-20		20-21		21-22		22-23		23-24	
	D	J	D	J	D	J	D	J	D	J	D	J	D	J	D	J	D	J
Klamath Falls	*	2	-2	-13	*	*	-2	-1	-16	*12	12	14	*3	-9	3	-6	10	-3
Yonna	-	-11	-15	-33	*	*	-17	-20	-29	2	-11	-13	-2	-27	-4	-7[f]	-	-
Chiloquin	-	-4	-17	-17	*	-1	-12	-9	-22	2	-2	-4	-5	-24	-4	-14	0	-16
Round Grove	-	-	-	-	-	-	-	-	-	-	-	-6	*	-22	1	-14	-2	-6
Lakeview	-4	-4	-14	-10	*	-1	-11	-8	-16	*	*	*	*	-11	*	-9	*	-8
Valley Falls	-9	-2	-6[n]	-15	*	-2	-13	-14	-31	*1	-3	-5	0	-23	*	-13	-4	-2
Fremont	-	-	-	-	-	-	-	-12	-39	-2	-18	-15	-15	-32	-12	-23	-8	-
Bend	-6	-19	-	-16	*	-4	-4	1	-25	*	*	*	-5	-10	-5	-4[f]	-9	-11
Prineville	-1	-26	-9	-14	*	-5	-10	-7	-32	*	-	-	-	-16	-11	-	-11	-5
Hay Creek	-	-	-	-	-	-	-	-	-28	-	-	-	-	-	-	-7[f]	-1	-14
Dayville	1	-12	0	0	*	-3	-1	-4	-33	*	*	*	-6	-18	0	*	*	-3
Prairie City	-10	-11	-8	-15	*	-17	-8	-7	-26	-1	*	-3[f]	-	-22	-6	-9[f]	2	-12
Heppner	*	-10	*	*	*	-7	*	*	-18	*	*	*	*	-13	-2	-1[f]	0	-8
Ukiah	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-21[f]	-3	-13
Joseph	-	-13	-	-8	*	-	-	1	-21	0	*	-2[f]	*	-14	-5	-	-	-
Wallowa	-13	-22	-10	-16	*	-13	-9	-6	-38	-5	*	-18[f]	*	-23	-20	-6[f]	5	-16
State Minimum---	-26	-27	-23	-40	-4	-21	-29	-25	-47	-28	-23	-20	-21	-39	-29	-25	-19	-24
State Mean------	31.0	18.9	26.6	22.3	40.0	34.6	29.4	30.2	23.1	31.6	32.0	30.2	29.3	20.1	28.3	31.9	30.2	25.9

Station	24-25		25-26		26-27		27-28		28-29		29-30		30-31		31-32		32-33	
	D	J	D	J	D	J	D	J	D	J	D	J	D	J	D	J	D	J
Klamath Falls	-6	*	*	*	*2	4	0	3	3	0	*	-7	*	*	0	-2	-10	-10[f]
Yonna	-17	*	*	*	1	5	1	0	-1	-3[f]	*	-14	*	1	-5	-2	-16	-16[f]
Chiloquin	-20	1	*	*	-10	-14	-10	-4	-4	-8	*	-16	-2	0	-8	-9	-19	-17[f]
Round Grove	-20	2	*	*	-	-25	1	0	-3	-	*	-15	1	-1	-4	-	-20	-
Lakeview	-16	1	*	*	-3	-4	-2	*	*	-4[f]	*	-15	*	-3	-15	-16	-16	-22[f]
Valley Falls	-28	*	*	*	-7	-12	-6	2	0	-7	*	-24	-7	6	-12	1	-34	-26[f]
Fremont	-	*	*	-2	-16	-19	-20	1	-12	-24[f]	*	-30	-8	-3	-15	-6	-	-39[f]
Bend	-19	*	*	*	-7	-17	-2	-3	*	-16[f]	*	-20	*	*	*	*	-10	-26[f]
Prineville	-32	*	*	*	1	-17	-2	1	*	-24[f]	*	-35	*	*	*	*	-19	-24[f]
Hay Creek	-26	*	*	*	-11	-21	-2	-3	*	-20[f]	*	-24	*	*	1	*	-15	-22[f]
Dayville	-25	*	*	*	-12	-14	-2	*	*	-14	*	-32	0	*	*	*	-17	-21[f]
Prairie City	-	-	-	-	-3	-24	-9	*	0	-18	*	-25	*	*	*	*	-15	-31[f]
Heppner	-10	*	*	*	-5	-13	2	1	*	-12[f]	*	-18	*	*	*	*	-13	-18[f]
Ukiah	326	-	*	-12	-26	-46	-20	-8[f]	-7	-39[f]	*	-45	-11	-6	-24	-16	-28	-54[f]
Joseph	-34	-2	*	*	-20	-29	-23	-5	-6	-17[f]	*	-27	-4	-4	-4	-4	-25	-29[f]
Wallowa	-22	1	*	*	-12	-25	-	-	-	-26	*	-35	-13	*	-13	-13	-24	-33[f]
State Minimum---	-53	-10	0[n]	-12	-26	-46	-23	-8	-17	-39[f]	-6	-52	-15	-11	-38	-41	-38	-54[f]
State Mean------	21.7	33.5	34.0	30.0	30.3	29.9	27.6	30.3	27.6	23.4	36.3	15.0	26.1	30.9	26.8	26.0	23.6	27.5

n - November record
f - February record

* = plus

January 1930 — Lowest mean temperature for any month ever recorded in Oregon. Long sustained cold. Snow on the ground. Wheat was protected.

December 1931 — Moderately low temperature. Snow above normal. Little damage to wheat.

January 1932 — Somewhat colder than usual. Snow on the ground. No wheat injury.

December 1932 — One of the most destructive cold spells in recent history. Ground bare. Widespread damage to wheat, shrubs and fruit trees. Average temperature formonth lowest since 1924.

February 1933 — Lowest temperature ever recorded in Oregon (-54°). Abundant snow on ground. Cold spell of short duration. No damage to wheat.

Further examination of the weather records indicates that these cold spells have affected different portions of eastern Oregon to a varying degree. Some years it is coldest in central Oregon, other years in southern Oregon, and in other years in northwestern Oregon.

If we examine the cold spells listed above more critically as to their character and effect in areas where we have infestation records, we find that cold weather which we might expect would produce beetle mortality is not of frequent occurrence. Table 45 lists the more important data for the last eleven important cold periods in southern and central Oregon. Of these eleven only four periods stand out as exceptionally cold ones; i.e., December 1919, December 1924, January 1930, December 1932, and February 1933.

Effect Upon Beetle Epidemics

The record of western pine beetle epidemics in southern Oregon is available since 1921 and has been estimated back to 1918. The fluctuations in volume of timber killed per acre on 10,160 acres of plots actually cruised each year in the region between Klamath Falls and Lakeview is shown in Graph 11. Along with this is shown the major cold spells during this period.

In the southern Oregon region there doesn't appear to have been any noticeable effect of earlier cold spells in halting beetle epidemics.

Table No. 45

Outstanding Cold Spells

Station		Jan. 1917	Dec. 1919	Jan. 1922	Dec. 1924	Jan. 1927	Feb. 1929	Jan. 1930	Dec. 1931	Jan. 1932	Dec. 1932	Feb. 1933
Southern Oregon	Length of Period	8	5	5	10	2	4	10	5	4	8	4
Klamath Falls and Lakeview	Minimum Temperature	-13	-16	-11	-16	-4	-4	-15	-15	-16	-16	-22
	Lowest daily Mean	*1	-6	*3	-1	*9	*7	-1	*2	*2	-4	-4
Central Oregon	Length of Period	2	4	2	9	2	4	7	0	0	3	2
Bend and Prineville	Minimum Temperature	-5	-32	-16	-32	-17	-24	-19	*	*	-19	-26
	Lowest daily Mean	*13	-13	0	-12	*4	-3	-7	*	*	-4	-7
Eastern Oregon	Kill of Wheat	Yes	0	0	Much	0	0	0	Little	0	Heavy	0

* = +

The 1919 freeze was followed by a drop in infestation but this may have been the normal trend. The freeze of December 1924 was followed by nearly twice as much infestation in 1925. The freeze of January 1930 was also followed by an increase in infestation in 1931.

However, if we consider the lowest average temperature which occurred in any one day, which is a measure of sustained cold, we find, on referring to Table 5 the following relationships:

Southern Oregon - Klamath Falls - Lakeview

	Lowest Mean For One Day	Effect on Broods
December 1919	-6	High mortality may have occurred. Infestation declined following year.
December 1924	-1	Buckhorn recorded 20% mortality due to freezing. Infestation doubled in following year.
January 1930	-1	No mortality observed. Infestation increased following year.
December 1932	-4	Mortality of from 65 to 85 percent.

Thus it seems probable that there has been no air temperatures in southern Oregon fatal to a high enough proportion of broods to have had any effect upon the trend of epidemics since December 1919.

In central Oregon cold weather is of much more frequent occurrence and this may help to explain why large areas of overmature ponderosa pine in just the right condition for beetle attack may have escaped injury except for such disastrous years as 1931 and 1932. Unfortunately we have no continuous record of barkbeetle epidemics in central Oregon to refer to, but examination of the record is of interest.

Central Oregon
Bend-Prineville

	Lowest Mean For One Day	
December 1919	-13	No report
" 1924	-12	Mortality of 80 percent. Infestation dropped from 130 to 35 M.B.M. per section (Jaenicke's report)
February 1929	-3	Infestation negligible
January 1930	-7	" "
December 1931	Above Zero	Heavy epidemic
January 1932	" "	" "
December 1932	-4	Mortality of from 50 to 85 percent

It is of interest to note that the freeze of January 1930 in the Ochoco region was more severe than the recent one of last December. No observations of beetle mortality were made, but almost immediately following this freeze the epidemic of 1931 and 1932 developed. This killed as high as 15 percent of the stand over large areas.

The evidence so far would indicate that in cases where minimum temperatures below zero are sustained for over 24 hours and a high percentage of brood killed, this does have an effect in reducing subsequent infestation of the western pine beetle. But that anything less than a 50 percent kill of brood has little or no effect upon the general trendof western pine beetle epidemics.

It is also equally clear that such reduction of brood by cold weather has no lasting effect upon epidemic trends and that these trends are primarily influenced by other factors.

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SUMMARY

The mortality of overwintering western pine beetle broods as a result of low winter temperatures has been known to occur since 1924, but its importance was scarcely realized until this winter when widespread destruction of broods resulted from sub-zero temperatures in eastern Oregon, eastern Washington and northern California.

Studies were immediately started to determine the general distribution of the brood mortality, the relation of air to bark temperatures, the effectiveness of different degree of cold under field conditions and the resultant effect upon the trend of beetle epidemics. Large series of bark samples were collected by Forest officers and others and sent in for examination for the immediate practical purpose of determining what changes should be made in control plans. The results of these examinations and the conclusions which have been reached thus far are covered in the present progress report.

Even under normal conditions, there is a mortality which occurs in the immature stages and during periods of beetle transformations. From an average of 432 eggs laid by the western pine beetle to each square foot of bark area only 63 adults normally emerge. This represents a reduction of about 85 percent. Most of this normal mortality occurs during the transformation periods. Winter freezing during the larval stage represents a sudden reduction over and above the normal mortality.

Under field conditions, mortality of western pine beetle larvae from freezing started when the bark temperature reached 10 degrees above zero and increased as the temperature dropped until 72 percent mortality occurred at - 17°F. The higher survival in the field than in previous laboratory tests by Miller may be due to a difference in duration of low temperatures, a difference in field as against laboratory conditions, a survival of hardy individuals or a more cold resistant strain of beetles in the Oregon pine region.

Field observations and laboratory tests indicate that the duration of cold to which larvae of the western pine beetle are subjected is important only in cases where the length of exposure is for periods of less than two hours. However, the duration of cold plays a very important part in the lowering of bark temperatures. A series of cold spells has the effect of weeding out the less resistant strains and could very well account for a more cold hardy race of beetles in the more rigorous portions of the beetles range.

Moisture tends to increase the mortality among larvae, especially the more immature. Mortality was found to be more than twice as heavy among broods of very small larvae still in the cambium, as among neighboring broods in the dry outer bark. In most cases where low temperatures prevailed, mortality among the small larvae was practically 100 percent.

Field tests showed that bark temperatures lag behind sudden changes in air temperature for one or two hours, and show a spread of from 9 to 29 degrees depending upon bark thickness and length of exposure.

Bark thickness is the most important factor modifying the relation between air and bark temperatures. The character of the bark, whether hard and flinty or soft and spongy also appears to be important.

Mortality was fully 30 percent greater on the north side of trees than on the south side even though the bark on the north side was found to be slightly thicker. This was due partly to less absorption of heat during the middle of the day and also the greater chilling effect of a north wind which blew during the cold spells.

Even for bark of the same thickness, mortality of larvae was from 15 to 20 percent higher in the upper portion of the trunk than in the basal 10 feet. This may be due to actually lower temperatures ten feet or more above the ground, or a difference in the character of the bark.

Theoretically air temperatures of 50 to 60 degrees below zero would be required to produce bark temperatures fatal to larvae of the western pine beetle in bark of all degrees of thickness. In the field an air temperature of 44 degrees below zero failed to kill more than 82 percent of the larvae in basal samples.

There are many factors which have an effect upon local air temperatures and the mortality which may result on any site. Under conditions of still air, slope and exposure, ridges or flats, forest cover and presence of snow all have an influence upon low air temperatures. When a strong wind prevails, air becomes mixed and temperatures tend toward uniformity over large areas. Since a strong wind accompanied the cold spell in December, this explains why no differences were found in brood mortality which could be attributed to the influence of site factors.

The cold spell of December 1932 lasted for eleven days and affected eastern Oregon and northern California but had little effect in Washington. The February 1933 freeze was of much greater intensity than the December spell but only lasted from 2 to 4 days. It affected both eastern Oregon and Washington.

To determine what percent of the barkbeetles were destroyed in any area it was necessary to determine not only the air temperature which prevailed but the effect upon bark temperatures for varying degrees of bark thickness and the proportion of bark of each thickness on a typical ponderosa pine Site IV area. From stem analyses by diameter classes and survey information as to the

distribution of beetle killed trees among the diameter classes, it was possible to compute the proportion of infested bark which would normally occur in five classes of bark thickness. It was found that practically 95 percent of all infested ponderosa pine bark is from 5/8 to 1½ inches in thickness. The proportion of bark in these half inch bark thickness groups was used to correct estimates of beetle mortality in cases where the samples did not follow the normal distribution.

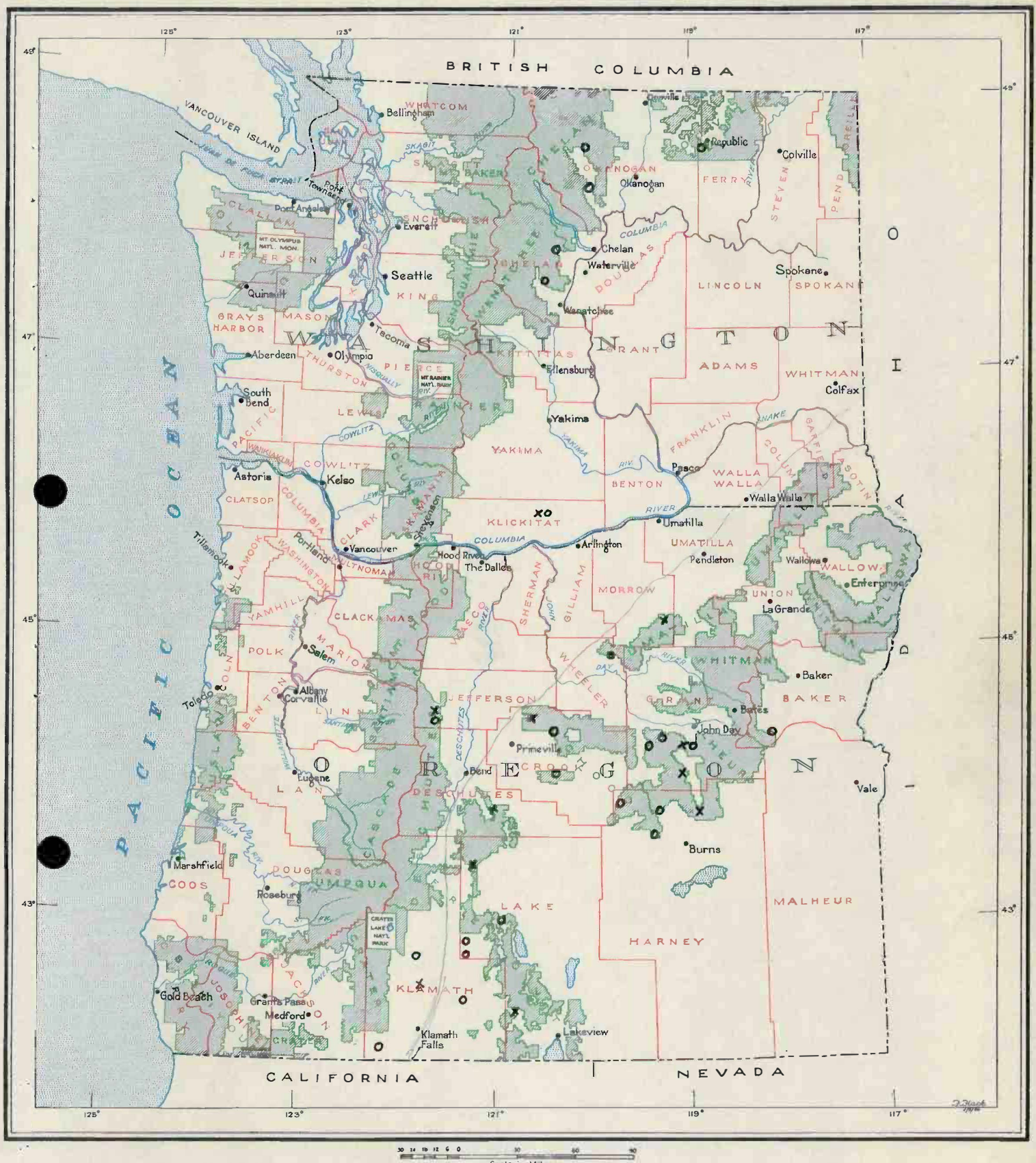
A total of 1200 bark samples were examined from 28 different areas in eastern Oregon and Washington. These represented 782 square feet of bark containing 147,619 living and dead larvae. Samples collected following both the December and February freezes showed brood mortality ranging from 25 to 92 percent. Forest areas in eastern Oregon showed a range in mortality from 33 to 92 percent and showed an average beetle mortality (exclusive of one transition area west of Klamath Falls) of 70 percent as determined from analysis of basal samples. Eastern Washington samples showed a range of from 25 to 80 percent and an average beetle mortality of 56 percent.

To put bark analysis work on a comparable basis and keep the maximum error of the mean within 10 percent, it was found that at least 45 samples containing 200 larvae each should be secured and analyzed from each area. In the later half of the work, forest officers collected 50 samples from each area so that this degree of accuracy was maintained.

On comparing the mortality which occurred on an area with the air temperature which prevailed in the vicinity, it was found that there was a very direct relationship between the two. Mortality started as air temperature reached zero. A kill of 50 percent of the brood resulted where air temperatures reached 20 degrees below zero; and 80 percent of the broods were destroyed at 32 degrees below. Total mortality was not reached even at 44 degrees below. It was found that fatal air temperatures paralleled fatal bark temperatures at an interval of about 10 degrees lower. That is, if a bark temperature of -12 degrees was found to kill 60 percent of the brood, an air temperature of -22 degrees was found to produce the same results.

While not conclusive, the brood mortality examinations from Oregon and Washington, which in effect amounted to a comparison of the results from the December and February freezes, indicated that the intensity of cold was of more importance than its duration. Apparently the short freeze of February was just as effective as the long period of cold in December wherever the same minima were reached. The data on this point is not conclusive as yet.

An examination of weather records from eastern Oregon show that winters with low temperatures have occurred at intervals of about three years and that since 1915 ten extremely cold winters have been experienced. Of these, four might be expected to have produced some killing of broods in the Klamath Falls-Lakeview area. The survey records on the other hand show no noticeable influence upon the trend of bark beetle epidemics for that region and infestations have more frequently increased following cold winters than decreased. Either these cold spells have not been low enough to prove fatal to a high proportion of bark beetle broods, or the destruction of the broods has been of only temporary benefit. In central Oregon, five cold winters since 1919 may have destroyed broods of the western pine beetle. The 1924 freeze is known to have killed 80 percent. However epidemics have followed within a year or two of such freezes so that it is evident that destruction of barkbeetles by cold weather has no lasting effect upon the trend of epidemics; and at best can only give temporary benefits.



LEGEND

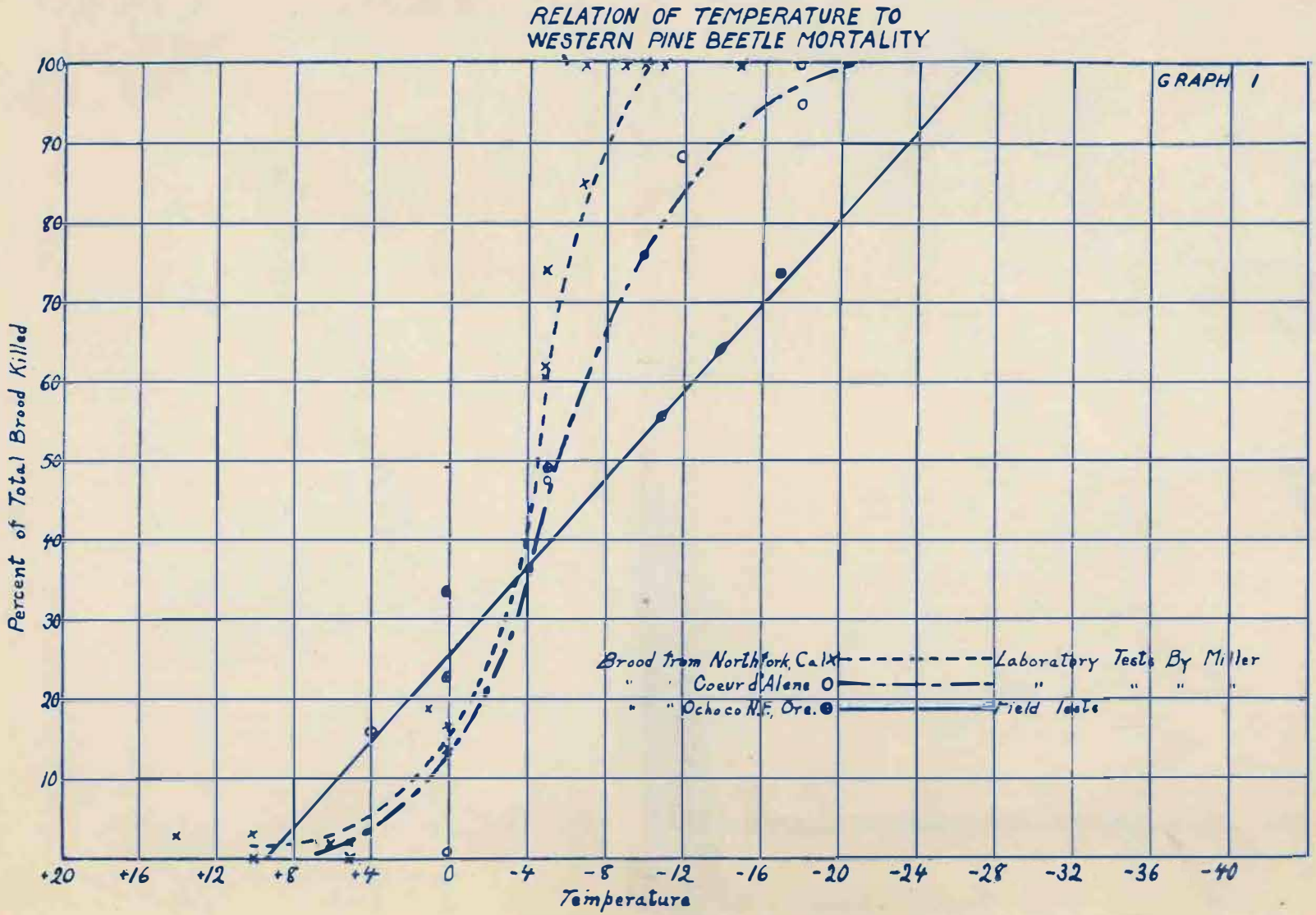
- State Lines
- National Forests
- County boundaries

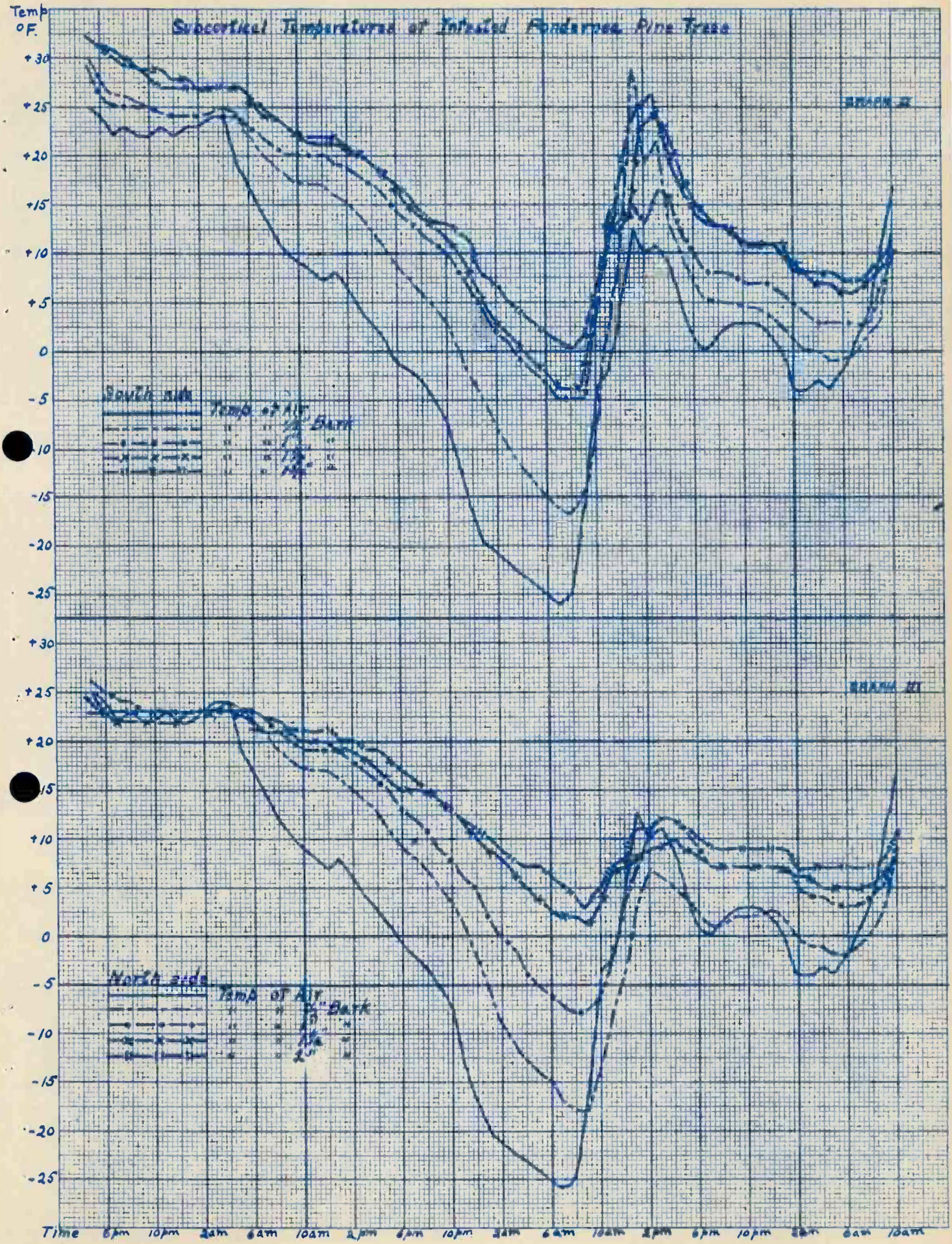
PACIFIC NORTHWEST FOREST EXPERIMENT STATION

Project **Localities represented by bark examinations**

X Brood mortality resulting from December 1932 freeze

O Brood mortality resulting from both December 1932 and February 1933 freezes.

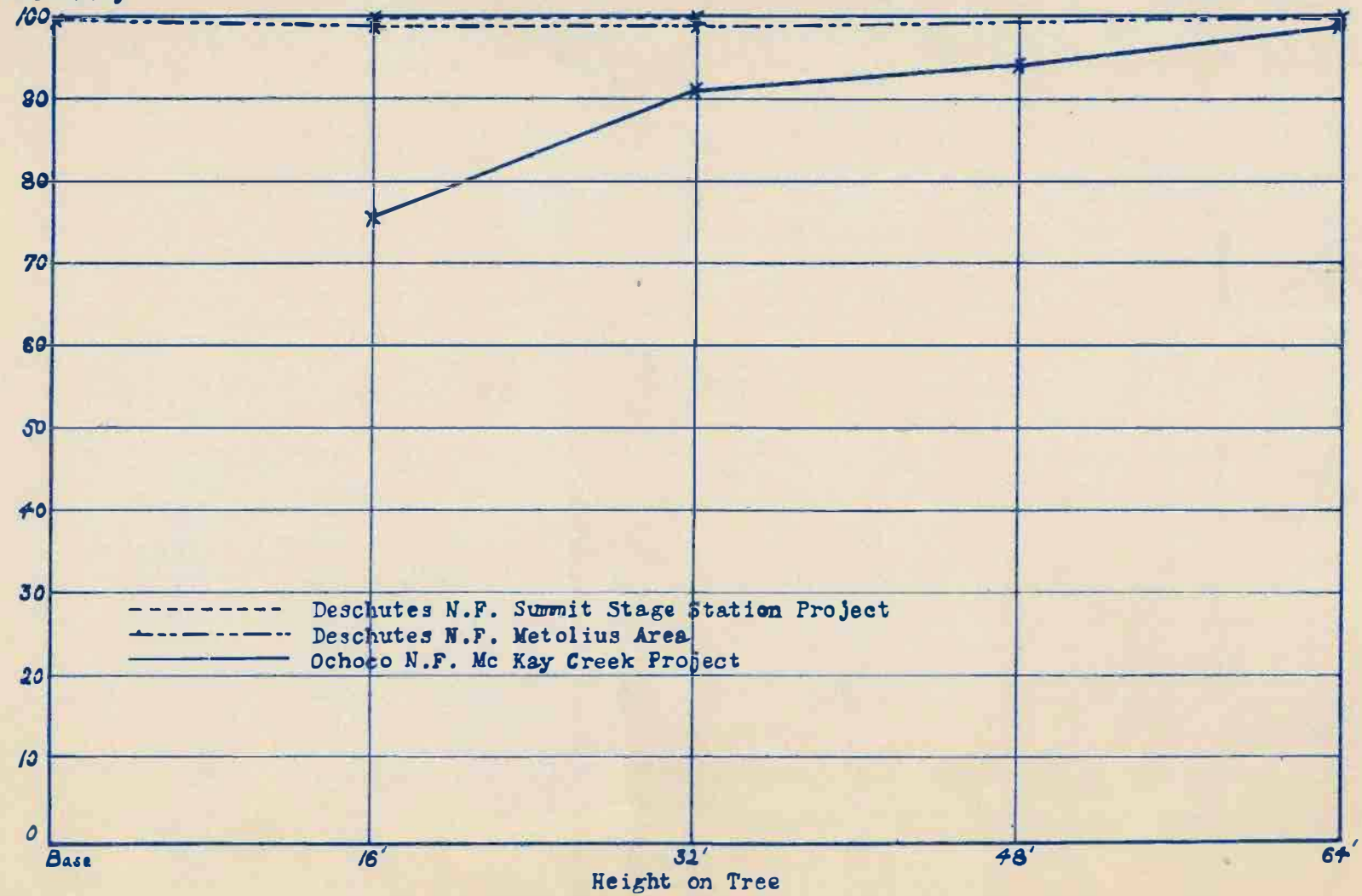

RELATION OF TEMPERATURE TO
WESTERN PINE BEETLE MORTALITY
GRAPH 1
Percent of Total Brood Killed
100
90
80
70
60
50
40
30
20
10
+20
+16
+12
+8
+4
0
-4
-8
-12
-16
-20
-24
-28
-32
-36
-40
Temperature
Brood from North Fork, Cal. X ---------- Laboratory Tests By Miller
" " Coeur d'Alene O ---------- " " " "
" " Ochoco N.F., Ore. ● ———— Field Tests


Subcortical Temperatures of Infested Ponderosa Pine Trees
Temp °F.
+30
+25
+20
+15
+10
+5
0
-5
-10
-15
-20
-25
South side
Temp. of Air
Bark
North side
Time
6pm
10pm
2am
6am
10am
2pm
6pm
10pm
2am
6am
10am
2pm
6pm
10pm
2am
6am
10am

Western Pine Beetle Brood Mortality
According to Height on Tree

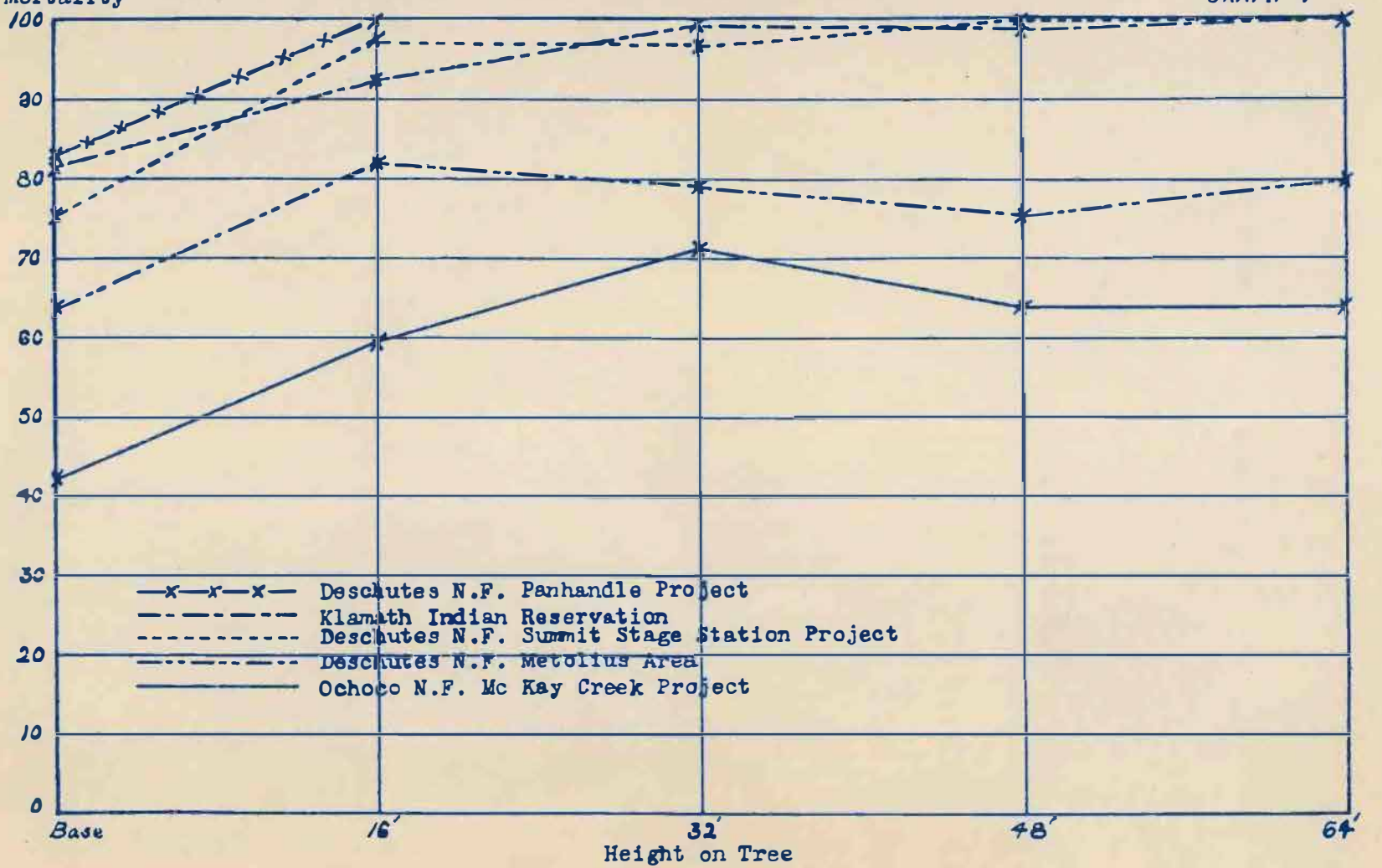
Bark 1/2" or less

GRAPH IV



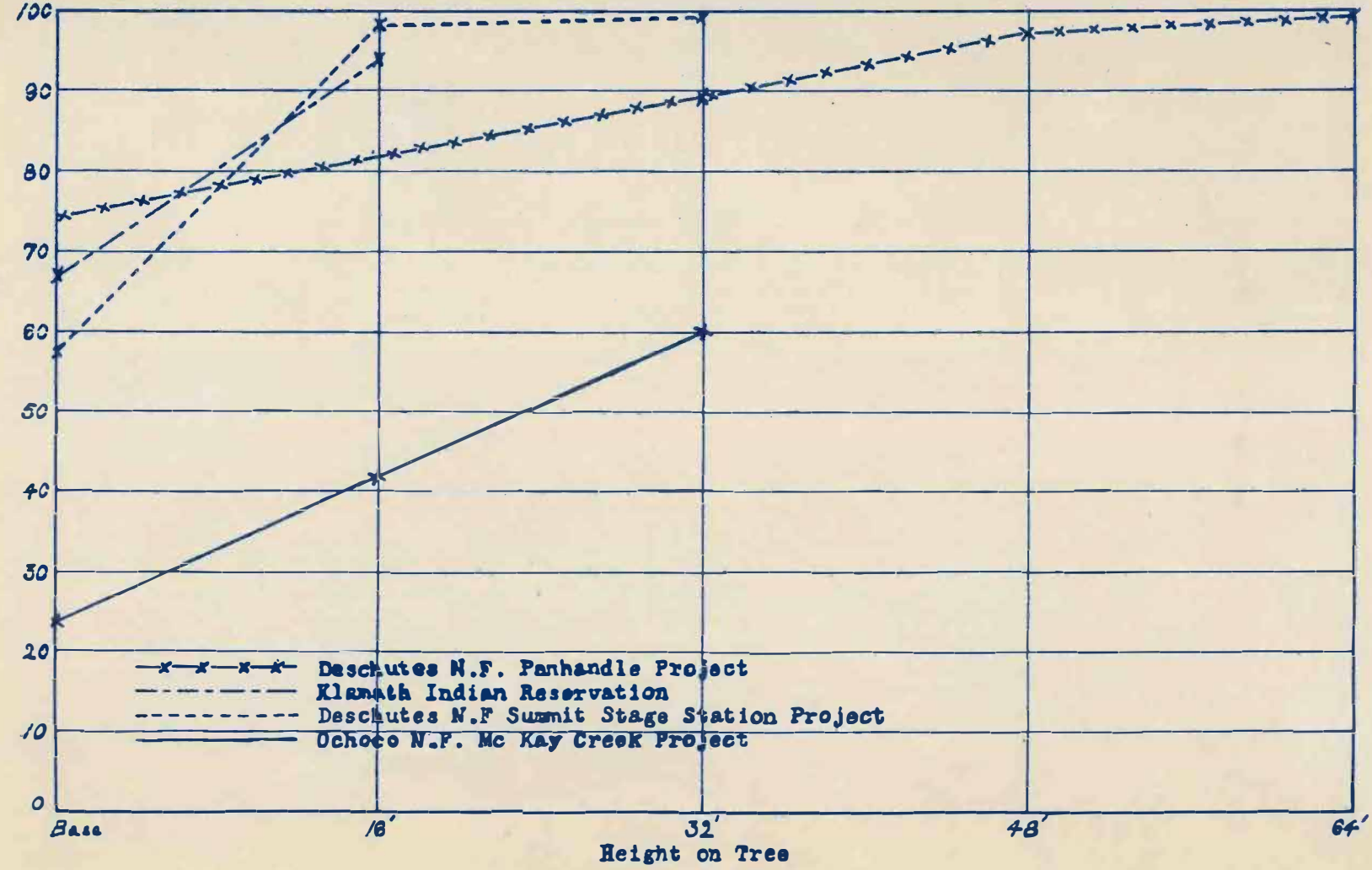
Western Pine Beetle Brood Mortality
According to Height on Tree

Bark 5/8 - 1"
GRAPH V



Western Pine Beetle Brood Mortality
According to Height on Tree

Bark 1 1/8 - 1 1/2"
GRAPH VI



Form 558 a (Rev. November, 1928)

TREE MEASUREMENTS

GRAPH VII

Project _____ No. _____

Locality EASTERN OREGON Sp. _____

Type PONDEROSA PINE Site IV D.B.H. 24 in.

Measured by _____ Total Ht. 92 ft.

Recorded by _____ 19___ Age _____ yrs.

VOLUME IN CUBIC FEET

	Entire Stem		Top diam. _____ i.b. o.b. Ht. to top _____ ft. Stump ht. _____ ft.					
	Sq.in.	Cu.ft.	Sq.in.	Cu.ft.	Sq.in.	Cu.ft.	Sq.in.	Cu.ft.
o.b.								
i.b.								
Bark								
Top o.b.								
Top i.b.								

VOLUME IN BOARD FEET

Scale as 16 foot logs with a trimming allowance of 0.3 foot. Scale top log as fraction of 16-foot log of same diameter.

Log No.	International ¼						As utilized Log Rule		
	Stump ___ ft. Top d.i.b. ___ in. Merch. L. ___ ft.								
	Length	Bd. ft.	Length	Bd. ft.	Length	Bd. ft.	Length	Gross	Net
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
Totals									
Top Length									

Computed by _____ 19___. Checked by _____ 19___

DIAMETER IN INCHES

← This column contains the converting factor to be checked when using 0 to 6 inch scale as an 0 to 60 inch scale

8-12-30
29
28
11
27
26
5-10-25
24
23
9
22
21
4-8-20
19
18
7
17
16
3-6-15
14
13
5
12
11
2-4-10
9
8
3
7
6
1-2-5

1.1.4
2.2.8.5
4.4.16.10

5 10 15 20 25 30 35
10 20 30 40 50 60 70
20 40 60 80 100 120 140
45 90 130
55 110
65

INSTRUCTIONS

Use a separate sheet for each tree. Indicate the combination of scales chosen by checking the cu. ft. per sq. in. converting factor which lies on line with both the diameter scale and the height scale used. Plot the i. b. and o. b. diameters of each section at its height above the ground. Write the diameter and height opposite each point plotted, as in the figure below. Beneath the height write the length of the next log and add, thus obtaining the height of the next section. Indicate the ends of the logs actually cut by arrows or by lines connecting the o. b. and i. b. points. If desired, when an increased scale could be obtained by bucking into other lengths the proper bucking may be indicated by dotted lines. Breaks and resultant cull may be indicated as well as base of crown, position of conks, forks and crooks, etc.

Draw smooth curves passing exactly through the points plotted. Treat the stump as a cylinder by drawing a horizontal line to the ground (vertical axis) from the curve at 1 foot (or 1.5 ft.). Measure the area between the axes and the curve, or any desired portion of it, by means of a planimeter. Without resetting the planimeter, make a second circuit to check the first; the areas thus obtained should not differ by more than one per cent. To obtain the volume in cubic feet multiply the area by the converting factor which was checked in the lower left corner. Enter the areas and volumes in the columns provided.

To determine the volume in board feet select the transparent board-foot scale (Forms 558-b, c, d, e, f, g), corresponding to the log rule and diameter scale used. Place the left edge at the stump height, with the two base lines coinciding. The board-foot volume of each log can be read from the vertical scale at the intersection of the taper curve with the vertical lines indicating the logs. If the last log is not a full 16 feet it should be scaled as a fraction of a 16-foot log of the same diameter, using the tables given on the forms. Columns are provided for recording the readings, using different log rules or top limits.

A column is provided for entering gross and net scales of material actually utilized, as scaled in woods by the log rule to be indicated. Other columns may be used to show the gross scale of the same logs by another rule, or the gross scale by the same rule had the tree been bucked into other lengths to secure better grades or utilization.

Totals of volumes by diameter-height classes, instead of individual tree values, should be used for computing bd. ft.-cu. ft. ratios, frustum form factors, cylinder or paraboloid [1] form factors, and all other percentage relations such as bark volume in per cent of peeled wood volume. Computations from group totals eliminate the error involved in averaging ratios or percentages, and incidentally reduce the amount of work necessary.

This form can also be used for analysis of periodic growth by plotting curves or diameters at each decade (or other period). When so used the age should be written along each curve.

[1] Paraboloids plot as straight lines.

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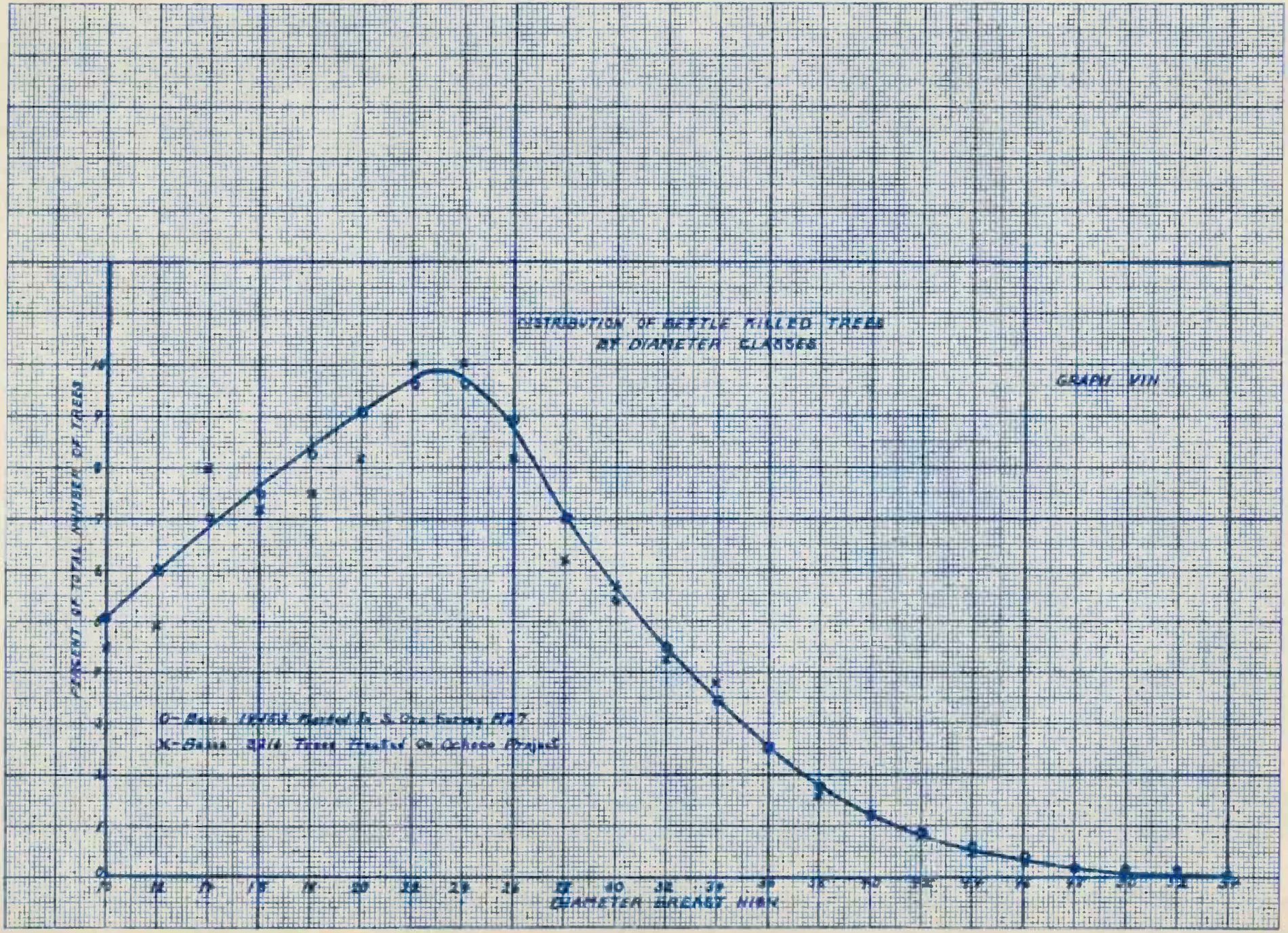
DIAMETER IN INCH

This column contains the converting factor to be checked when using the 0 to 6 inch scale as a 0 to 6

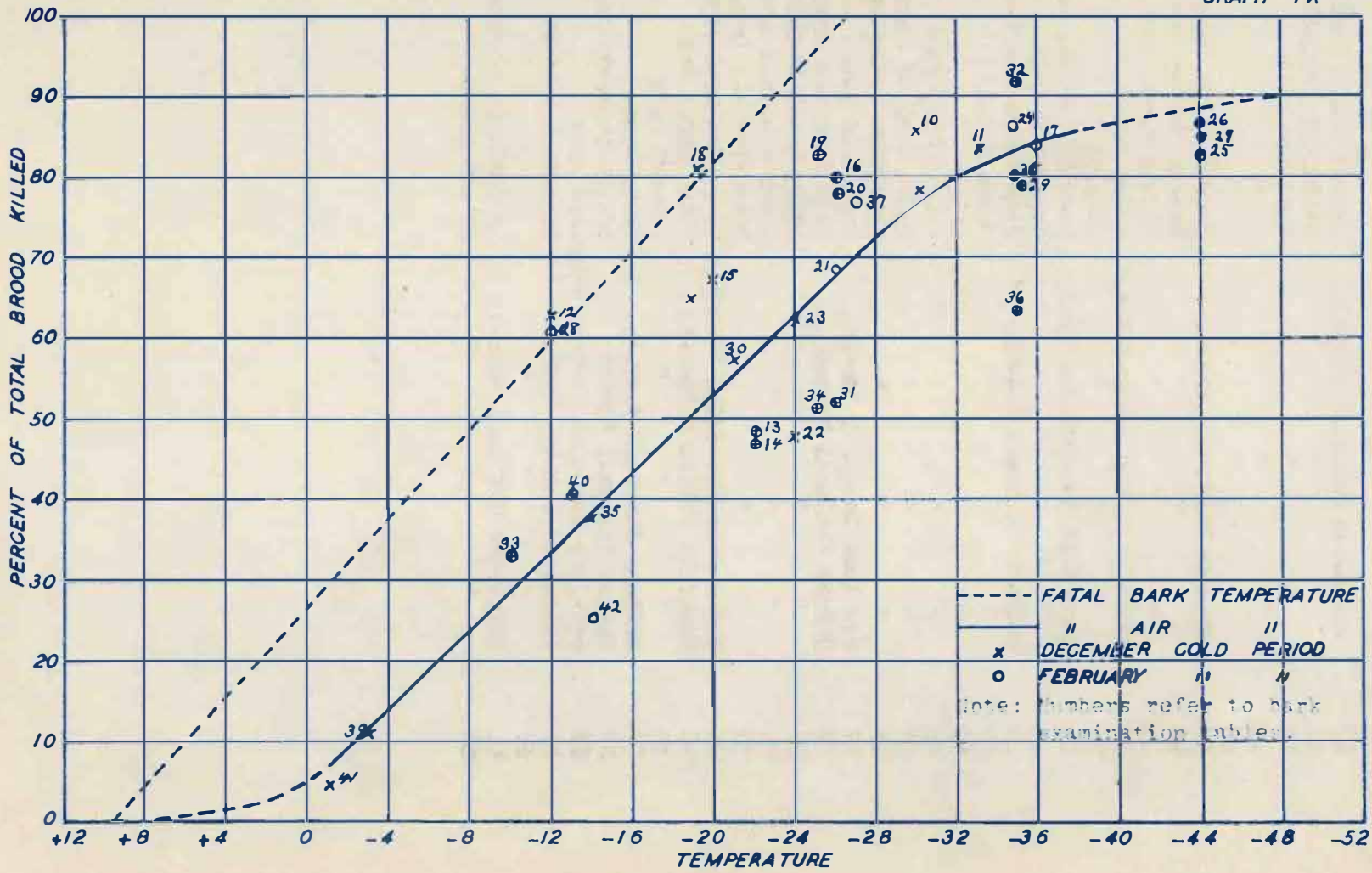

DISTRIBUTION OF BEETLE KILLED TREES
BY DIAMETER CLASSES
GRAPH VIII
PERCENT OF TOTAL NUMBER OF TREES
DIAMETER BREAST HIGH
O-Based (1938) Marked In S. Ore. Survey #37
X-Based 1938 Trees Treated On Cohoes Project

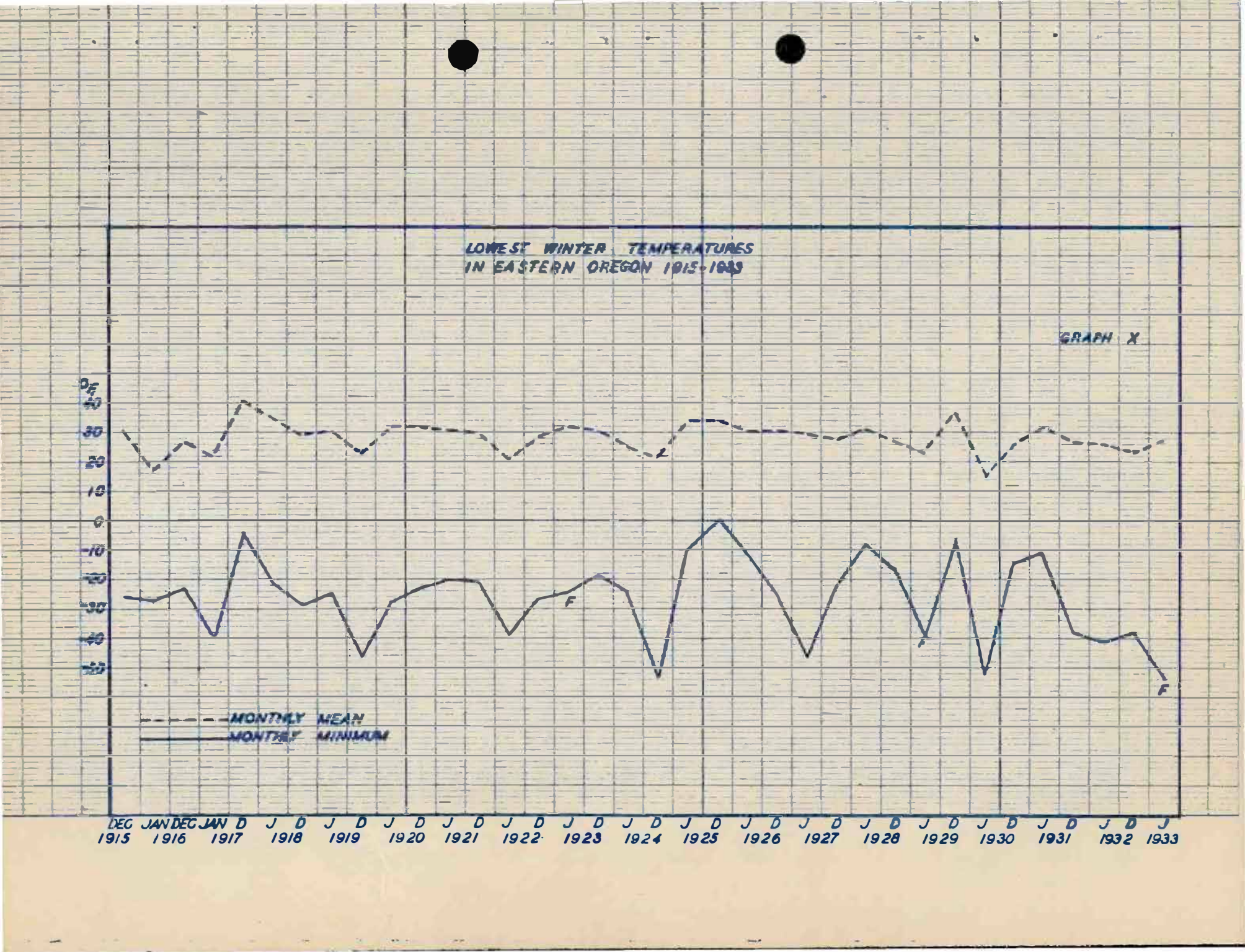
Localities Represented in Graph IX
Brood Mortality Examinations.

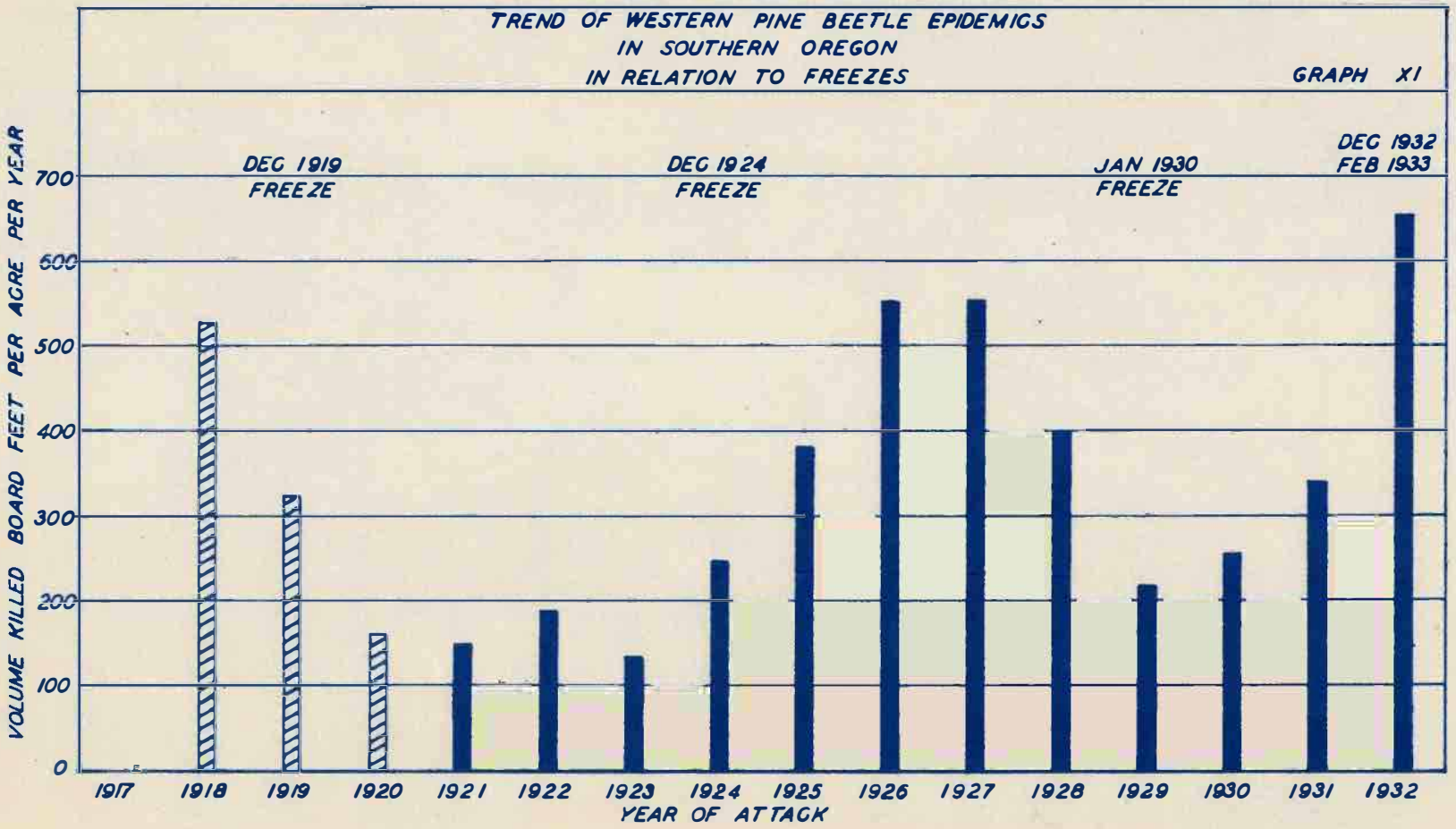
Table No.	Forest	Area.
10	Deschutes National Forest,	Summit Stage Station.
11	" " "	Panhandle Project
12	" " "	Metolius Area
13	" " "	" "
14	" " "	" "
15	Fremont National Forest,	Quartz Butte Area
16	" " "	Quartz Valley Area.
17	" " "	Silver Creek Area.
18	Klamath Indian Reservation,	Modoc Point.
19	" " "	General
20	Long Bell Reservation Tract,	Lamm Lumber Co. Area
21	" " " "	Long-Bell Area
22	Malheur National Forest,	Bear Gulch & Officer Creek.
23	" " "	Burns Area.
24	" " "	" "
25	" " "	Bear Valley Sale Area
26	" " "	South Fork of John Day River.
27	" " "	Murderers Creek Area.
28	Mt. Hood National Forest,	Wapinitia Area.
29	Ochoco National Forest	Snow Mountain Area.
30	" " "	McKay Creek Project
31	" " "	Maury Mountain Area
32	" " "	Snow Mountain Area
33	Rogue River National Forest,	Kene-Pinehurst Area
34	Umatilla National Forest,	Ditch Creek Area
35	" " "	Heppner Area
36	Whitman National Forest,	Unity Area
37	Chelan National Forest,	Twisp-Winthrop Area
38	Colville National Forest,	Tonasket Area
39	Klickitat County, Wash.	Eastern & Western Lbr. Co. Tract.
40	" " "	" " " " "
41	Wenatchee National Forest,	Leavenworth Station
42	" " "	Entiat Area.

RELATION OF TEMPERATURE TO
WESTERN PINE BEETLE MORTALITY

GRAPH IX




LOWEST WINTER TEMPERATURES
IN EASTERN OREGON 1915-1933
GRAPH X
°F
40
30
20
10
0
-10
-20
-30
-40
-50
F
MONTHLY MEAN
MONTHLY MINIMUM
DEC 1915
JAN DEC 1916
JAN 1917
D J 1918
D J 1919
D J 1920
D J 1921
D J 1922
D J 1923
D J 1924
D J 1925
D J 1926
D J 1927
D J 1928
D J 1929
D J 1930
D J 1931
D J 1932
J 1933


TREND OF WESTERN PINE BEETLE EPIDEMICS
IN SOUTHERN OREGON
IN RELATION TO FREEZES
GRAPH XI
DEC 1919
FREEZE
DEC 1924
FREEZE
JAN 1930
FREEZE
DEC 1932
FEB 1933
VOLUME KILLED BOARD FEET PER ACRE PER YEAR
0
100
200
300
400
500
600
700
1917
1918
1919
1920
1921
1922
1923
1924
1925
1926
1927
1928
1929
1930
1931
1932
YEAR OF ATTACK